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DSTO-TR-1638

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ABSTRACT

An initial investigation of the nature of future close combat derived and tested two possible enduring mechanisms for the conduct of close combat – attrition and suppression. A suite of analytical tools, including closed simulations, wargames, mathematical analysis and historical analysis, was used to establish loss exchange ratios (LER) for a number of scenario variants. The LER was used as the primary measure of effectiveness to investigate the dependence of combat success on the composition of the combined arms teams and the dependence of combat outcome on terrain. The analysis concludes that attrition is the dominant mechanism in "open" terrain and suppression in "close" terrain and that this is likely to endure, while improvements in sensors and weapon systems will gradually change the terrain types that are considered "open" and "close". The utility of combined arms teams was demonstrated by a significant reduction in absolute casualties and LER.

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Attrition and Suppression: Defining the Nature of Close Combat

Executive Summary

Introduction. The Close Combat Study was conducted in response to a short term study request (STSR) from the Director General Future Land Warfare (DGFLW) to examine the possible nature of close combat in 2015. The initial results were reported to the DGFLW in March 2001, and presented at the 2001 Land Warfare Conference. This report completes the initial phase of an extended study resulting from the initial request. In the research request for this study the need to conduct close combat was assumed, based on other studies.

These studies include those sponsored by the Australian Army in support of analysis of the Army 21 concepts (1995/1996), The Restructuring the Army (RTA) series of trials (1997/98) and the Army Experimental Framework (AEF) (1999/2000 and extended to 2003). The outcomes of these studies and the subsequent military analysis, reported to the Minister of Defence, concluded that the capability to conduct close combat would remain central to the successful prosecution of land operations and that combined arms teams were the most effective and efficient organization for undertaking warfighting operations. The military analysis supports the notion that the land force should maintain a close combat capability.

However, in keeping with other western militaries, the ADF and the Australian Army are investigating the changing nature of aspects of warfare, in particular the requirements for close combat, due to the technological advances anticipated by 2015 and beyond. In effect this is one of the fundamental points facing the world's Armies in the "Transformation" or "Revolution in Military Affairs". In terms of land combat this translates to the following significant question:

> "How will advances in sensor and information technology change the nature of close combat and the capabilities required"?

This question has been addressed here by defining an initial basis for studying the nature of close combat, constructing a model that includes the known principal mechanisms, characteristics, and factors affecting the conduct of close combat, and finally determining the possible changes due to technology in 2015.

In particular this study examined the nature of close combat in 2015 and its impact on the mix and balance of capabilities for close combat in open and restricted terrain.

Definition. Following a literature survey, a definition for close combat was derived in consultation with subject matter experts. For this study close combat was defined as combat where all elements participating in the combat can engage (and possibly inflict damage on) the other opposing elements with direct fire weapons.

The impact of indirect fire weapons on close combat was considered, but the positioning of the indirect fire elements was constrained, consistent with the definition.

Method. A model of close combat was developed as a framework for interpreting information from a number of sources including mathematical representations, analysis of historical combat data, simulations of generic light infantry company attacks on infantry platoon positions, and simulations of a number of specific company attack scenarios, in open, restricted and urban terrains.

The model of close combat developed included:

- two primary defeat mechanisms applicable to attacker and defender: attrition and suppression;
- appropriate offensive and defensive responses; and
- a primary variable: the level of obscuration of the intervening environment.

Using this model the impact of three force elements, infantry (small arms), armour (protected direct fire) and artillery (indirect fire) were investigated. The model of the physical environment used simplified definitions of terrain and vegetation where open terrain is defined as terrain where likely detection ranges are greater than effective weapon ranges and restricted terrain is where likely detection ranges are shorter than effective weapon ranges.

Results. The results of the study indicate that

1. The nature of close combat depends on the terrain and differs significantly between open and restricted terrain. The mechanism of personnel and materiel attrition can be expected to dominate combat in open terrain, whereas suppression is the dominant defeat mechanism in restricted terrain. This difference appears to be due to the difficulty of acquiring targets in restricted terrain. Furthermore, the study indicates that the optimal role of infantry weapons in defence should be in destroying attacking systems, whereas in attack, infantry weapons are optimally employed in modes that suppress the defence until the attack closes with the defence.

2. In both open and restricted terrains, the addition of any supporting arms in intimate support roles significantly reduces casualties and improves effectiveness, measured by the loss exchange ratio (LER). This is the case regardless of whether the supporting arms contribute to the attack or the defence.

3. The scale of close combat differs between open and restricted terrains. In open terrain there is a possibility of close combat being conducted as 'single' large battles where many defenders interact through direct fire with many attackers. In restricted terrain close combat is more likely to involve of a number of 'few on few combat situations, or 'mini-battles'. This is largely due to problems of target acquisition. Further study is required to identify all issues.

4. The balance between the assault element and the intimate support elements also differs between open and restricted terrain; in the simulations we found that in open terrain the size of the infantry element can be reduced and effectiveness, measured by the LER, increases. To some extent this is supported by anecdotal historical evidence.

Capabilities. Offensive close combat requires a capability to assault and engage in the close combat. Modelling and historic analysis agree that success in offensive close combat is significantly improved by capabilities that:

- provide intimate support to the assault, and destroy threats to the assault group after all remote (from close combat) supporting fire has ceased;
- provide direct fire to support the assault as it finally closes with the defence; and
- provide indirect fire support to suppress the enemy's defences as the assault closes.

Defensive close combat requires a capability to hold ground. Success in defensive close combat is significantly improved by capabilities that:

- support the defence by destroying assaulting systems, and
- provide indirect fire support to suppress the assaulting force.

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Glossary

AEF	Army Experimental Framework
AFS	Aerial Fire Support
AGS	Armoured Gun System
ARH	Armed Reconnaissance Helicopter
ASLAV	Australian Light Armoured Vehicle
CAEn	Close Action Environment
CASTFOREM	Combined Arms and Support Task Force Evaluation Model
CATDC	Combined Arms Training and Development Centre
CB	Counter-battery
CQB	Close quarter battle
DGFLW	Director General Future Land Warfare
DOAC	Defence Operational Analysis Centre
F|F	firer/firer model
FT|FT	firer target/firer target model
LER	Loss Exchange Ratio
Mot Coy	Motorised Company
MSE	Mean square error
OPFOR	opposing force
ORBAT	Order of Battle
Ptl	Patrol
RTA	Restructuring the Army
Sect	Section
STSR	short term study request
UK	United Kingdom
USMC	United States Marine Corps
WWI	World War I

1. Introduction

The Close Combat Study was conducted in response to a short term study request (STSR) from the Director General Future Land Warfare (DGFLW) with the aim of exploring the nature of close combat in 2015 and its impact on the combat force. In particular it aimed to provide information on the mix and balance of capabilities for close combat in open and restricted terrain. The objectives of the study were to:

- define close combat,
- examine the functions of close combat,
- examine the demands of close combat,
- examine the level of force required, and
- examine the capabilities required.

The context for the study was provided by the Restructuring the Army (RTA) Trials, conducted between 1997 and 2000, in response to the Army in the 21st Century Review (A21) (Wallace 1998, Australian Army 2000), and evolved into the current Army Experimental Framework (AEF) program. They were designed to inform decisions on capability development for the Australian Army for the first decade of the 21st Century and were aimed at a force design that was effective, affordable and sustainable. The specific insights from the RTA Trials that framed the close combat study are (Australian Army 2000):

- **Combined Arms Teams.** "All successful ground force tactics are based on achieving or defeating combined arms effects". Combined arms effects, supported by an integrated C4ISR system and joint assets proved fundamental to success in conflict and are important determinants of both efficiency and effectiveness.
- **The Tyranny of Terrain.** RTA Phase 1 showed that in close terrain the application of precision fires from standoff distances was not generally possible. However, in more open terrain, standoff precision weapons delivered by artillery, helicopters and aircraft demonstrated their expected advantages (RTA Phase 2), though weapon time of flight and third party designation proved problematic. In summary, precision firepower reduced casualties in favourable conditions (open terrain), however precision weapons were limited by the technologies to detect and monitor the likely targets (through the entirety of the engagement cycle) and therefore could only supplement traditional integral firepower provided by mortars, artillery and tanks in areas where detection ranges were limited.
- **Force Mix and Firepower.** RTA Phase 2 (AEF 99/00) demonstrated that in open terrain a light and mobile task force was able to match heavy forces by using precision delivered munitions, fused with a web of sensors and a networked command and control architecture. While this appeared inconsistent with the Phase 1 results (the "Tyranny of Terrain") this result is consistent with an offensive philosophy that advocates that ground forces will seek to kill at standoff ranges where possible, however it is balanced by a defensive philosophy that the defender will seek to shroud

themselves in the terrain or civilian populations to minimise the effect of long-range precision fires.

The analysis in these three areas led to the recommendation that:

> *"[while] the thoughtful addition of advanced technologies can markedly enhance land force capability ... in general, the effect of terrain still required that the land force be able to fight and win close combat..."*

A suite of analytical techniques was drawn together from across disciplines to study the effectiveness of combat systems and the interactions and interdependencies between the contributing systems. The suite of techniques included a literature review, including UK analysis of historical combat data (Rowland 1990, Thornton 1993), Lanchester and Close Action Environment (CAEn) modelling of a generic light infantry company attacking an infantry platoon, and a number of complex company attack scenarios, using CAEn, Combined Arms and Support Task Force Evaluation Model (CASTFOREM) and Janus, in open, restricted and urban terrains (Bowley and Brewer 2000, Tailby et al 2001a and b, Lovaszy et al 2000, James et al 2002).

The study developed and used a model of close combat based on:

- two primary defeat mechanisms: attrition and suppression and appropriate defensive responses, and
- a primary variable (the physical environment[1]).

Using this model the impact of three force elements, infantry (small arms), armour (protected direct fire) and artillery (indirect fire) were investigated.

The results of this study will contribute to development of combined arms teams for close combat in complex terrain. The initial results were reported to DGFLW in March 2001, and presented at the 2001 Land Warfare Conference (Bowley, Castles, Ryan 2001b). This report completes the initial phase of an extended study resulting from the initial request.

2. A Model of Close Combat

2.1 Definitions

Many of the terms used in this study have specific definitions that may differ slightly to those used in other work. The following definitions apply in this report.

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[1] It was assumed for this study that the impact of manoeuvre was to establish favourable conditions for close combat and that for manoeuvre to be successful without close combat the forces manoeuvring had to poss a significant threat, and this was determined as the capability to conduct close combat.

2.1.1 Close combat

The definition of close combat that was used in the study was adopted from the Combined Arms Training and Development Centre (CATDC) WinNow Papers (CATDC 2000), and uses the concepts of terrain expressed in Section 2.1.2.

> *'Actions that place friendly force elements in varying terrain and in immediate contact with the threat; where direct fires, supported by indirect fires, are applied to strike, shape and/or shield to defeat or destroy enemy forces or seize and retain decisive points'.*

From this definition of close combat the purpose of close combat was deduced as:

> *'...to destroy enemy forces and/or to seize and hold ground.'*

Importantly this definition establishes a consistent purpose for close combat across the core combat functions of shape, strike and shield. The operational effect generated by destroying enemy forces or by seizing ground was beyond the scope of this study.

2.1.2 Terrain

Analysis of the RTA trial data led to the simplified definitions of terrain and vegetation used in this study (Bowley and Brewer 2001). The definitions relate the impact of terrain and vegetation to the range of direct fire weapons and the detection range of sensors. Accordingly the following definitions were adopted for this study.

- **Open terrain** is defined as being where likely detection ranges are greater than effective weapon ranges, e.g. flat desert areas.
- **Restricted terrain** is where likely detection ranges are shorter than effective weapon ranges, e.g. jungle or mountainous areas.
- **Complex terrain** is effectively a 'patchwork' of these basic terrain types.

Details of how the vegetation model in CAEn was used to represent these terrain types are in Section 2.3.

2.1.3 Attrition and suppression

Consistent with the findings of the UK Historical Study (Rowland 1990, Thornton 1993), the present study assumes that the primary mechanisms of close combat are attrition and suppression. The definitions for attrition and suppression that are used came from doctrine (ADFP 101) and are given below.

- **Attrition** is the reduction of the effectiveness of a force caused by loss of personnel and materiel
- **Suppression** is that activity which neutralises, or temporarily degrades the enemy in a specific area by physical attack and/or electronic warfare (noting that electronic warfare was not considered in this study).

2.2 Assumptions

The following assumptions have been made to allow a simplified model of close combat to be developed to support modelling of close combat with entity based combat simulations.

The scope of the initial phase of the study was constrained, firstly, by the assumption that the current doctrinal techniques of the attack and area defence will remain appropriate within the timeframe considered[2]. Secondly, that the stages of the attack and conduct of the defence will remain valid for 2015 (however their relative importance may change). This assumption is valid based on a definition of close combat that specifically excludes precision attacks.

The Attack. There are four stages to an attack:

- The preparatory stage.
- The assault stage.
- The exploitation stage.
- The reorganisation stage.

These are balanced by complementary stages of a defence.

An Area Defence. The conduct of a defence is considered in three stages:

- The preparatory stage. When the enemy is closing with the main defensive position and making preparations for attack.
- The assault stage. When the enemy is attempting to penetrate through the defence of the main position.
- The counter-attack stage. If and when an enemy assault has achieved some success but has been held, an attack may be launched to regain ground.

Consistent with a doctrinal approach to sub-unit operations, it is assumed that a commander planning an assault will plan by considering the appropriate mix of the following capabilities required for the conduct of close combat from the following, based on an appreciation of the terrain and enemy dispositions:

- Indirect fire support.
- Direct fire support.
- Intimate support.
- An assault group.
- Mobility support and denial.

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[2] This assumption is probably not overly constraining – considering that the current capability development program articulated in the DCP2001 do not significantly alter the tactical combat capabilities of the land force.

The implied assumption that these capabilities are required for close combat is tested in this study by investigating the impact of each element during the assault. The exception to this is that the requirement for an assault force is assumed (based on the definition of close combat) and therefore only the size of the assault force as part of the combat mix is investigated. The requirement for mobility support and denial was not investigated in this study.

These capabilities were represented by the following surrogates in the models:

- 81 and 82 mm Mortars for indirect fire support;
- Aerial Fire Support (AFS) Helicopters for direct fire support;
- Leopard AS1 and T72 for direct fire support;
- Light Infantry (with small arms, machine guns and sniper rifles) as the assault group.

2.3 Description of close combat

The model of close combat used in this study was based on the definitions above. Importantly, the definition of close combat used here reflects combat in which the direct fire weapon systems of each side are able to effectively engage each other. Indirect fire systems contribute their supporting fire to close combat but themselves are not considered 'in' close combat unless the other side can bring direct fire to bear. This highlights the essentially personal nature of close combat: that of being engaged with lethal force by the enemy while you attempt the same[3]. Importantly the effective use of precision weapons, both direct and indirect, is likely to be greatest in the preparatory phase, and in shaping the situation prior to the assault. We note again that the earlier studies identified the need for stand-off methods of combat and the need for close combat, thus, this model excludes precision engagement through a combination of remote sensors and engagement systems to focus on the factors effecting the force mix required of close combat. It deals with close combat as the means of destroying the enemy or seizing and holding ground when there is a requirement to close to within the engagement range of the enemy.

To assist the analysis the doctrinal sequence of close combat in the attack has been modified to:

1. The preparatory stage,
2. The assault stage,
3. The fight through stage (doctrinally part of the assault),
4. The exploitation stage, and
5. The reorganisation stage.

[3] Close combat by this definition is different from Close Quarter Battle (CQB), which is a subset in this definition – see Figure 1.

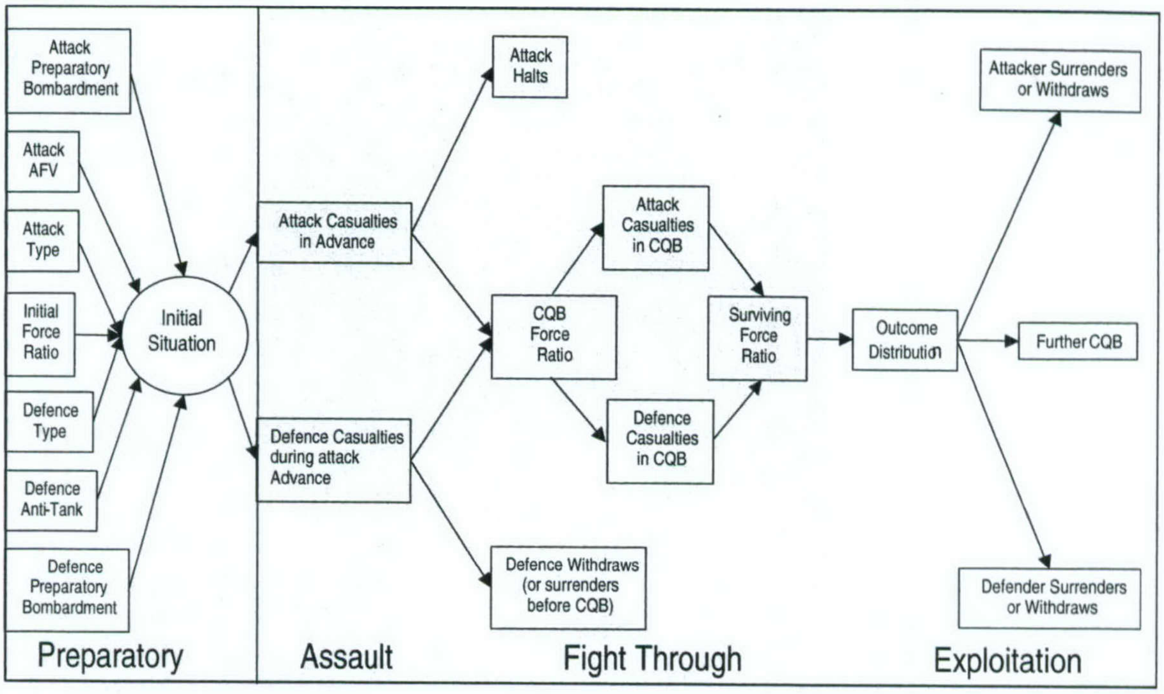

Figure 1: Diagram of sequence of close combat (after Rowland 1990)
CQB – Close Quarter Battle

This sequence is defined in analytic terms in Figure 1, an adaptation from Rowland (1990). The "fight through" stage correlates with Rowland's CQB phase. This study is particularly concerned with the assault and fight through stages of the attack and the study conclusions are based on the analysis of these stages. The reorganisation and counter attack aspects of close combat were not investigated in this study, as they occur essentially as the result of successful close combat in attack (reorganisation/exploitation) or defence (reorganisation/counter attack).

Vegetation Model

As discussed in the previous section, one of the elements normally considered by a commander planning an assault is the terrain. Previous studies (Rowland) have shown the close dependence of the terrain complexity on the combat mix. It was necessary therefore to include terrain modelling as part of our study. The CAEn simulation was used as a modelling basis. CAEn includes a discrete time step closed modelling simulation of combat that focuses on sub-unit level dismounted infantry operations. The probability of line-of-sight ($PLOS_R$) at any given range (R) of a target caused by obscuration by vegetation over that range is modelled as a power function based on a known probability of line-of-sight for a grid size ($PLOS_G$), equation (1):

$$PLOS_R = PLOS_G^{\frac{R}{G}}, \qquad (1)$$

where G = grid size (m) of the terrain used, which is the granularity of the representation.

It should be noted that CAEn uses the probable percentage of *cover* provided by the vegetation in its database rather than the percentage of *line-of-sight*. The relationship between these two values is

$$P(cover) = 1 - P(LOS). \qquad (2)$$

CAEn data files define the heights and simple culture type of each layer of vegetation for both complex and simple cultures. Each vegetation type is represented in a block of data with the number of vegetation layers, the upper and lower bounds of those layers and the culture code for each of those layers. For this study the open terrain did not contain any vegetation and the restricted terrain had a single layer of 35% cover. This choice of vegetation density gave a visual detection range for a standing target of approximately 50 m for the unaided human eye.

2.4 Postulates

The study examined four postulates.

1) Aimed fire will be the dominant mechanism for achieving attrition of the opposing force in open terrain and area fire will dominate in restricted terrain.
2) The terrain, and specifically the relationship between the detection and engagement ranges, determines the characteristics of close combat.
3) Support assets provide a significant improvement in the loss exchange ratio and in particular reduce infantry casualties.
4) The impact of adding different support assets is cumulative.

Importantly the postulates are not formally tested as null hypotheses in the entirety of the study or through repeatable experiment. They are tested by only one of the analytical tools, i.e. a series of generic CAEn scenarios.

3. Method

3.1 Techniques

The main analytical techniques used to establish a robust set of arguments relating to the postulates in the study were:

- historical studies
- Lanchester equation analysis
- generic and specific combat simulations
- wargames

A suite of analytical techniques was drawn together from across disciplines to study the effectiveness of combat systems and the interactions and interdependencies between the contributing systems. The suite of techniques used includes mathematical models of combat, high level combat simulations (both specific and generic scenarios), game theory and historical studies. Importantly, the postulates are tested by only one of the analytical tools, a series of generic CAEn scenarios[4].

The confidence in the use of the scenarios was increased by correlating the results of the simple CAEn scenarios with Lanchester's mathematical models of combat. The rationale was that while Lanchester equations do not model the richness of combat, analytical solutions are possible, and if the results of simple CAEn simulations meet the assumptions implicit in Lanchester we can have more confidence in the internal validity of the simulation.

In other more complex CAEn scenarios it is difficult to formally quantify the internal uncertainties, however the overall results can be assessed against other sources of data. The confidence in the simulation is informally reinforced by the absence of any evidence refuting the trends from other studies. In this way, the results of the CAEn generic scenarios were compared to the results from two separate detailed CAEn studies, and analysed together with the results from a CASTFOREM study and the insights from a historic analysis of formal assaults conducted by Rowland (1990).

The choice of the types of generic scenarios used was guided by the interpretation of the specific scenarios, historic studies and the results of the previous generic scenario; hence a type of iterative heuristic search was used to generate the insights. Several variations outside of the heuristic search were computed, as a test of the reinforcing nature of the heuristic. Errors inherent in extrapolation were minimised by developing subsequent variants of the CAEn generic scenario based on the specific study results and by correlating the results of all the studies to produce the insights (Bowley, Ryan and Castles 2001).

A relatively simple conceptual model was constructed to identify the enduring characteristics of combat and used to analyse how a contemporary force conducts close combat. Once the underlying nature of these characteristics was derived, the impact of the changes in force structure and technology on the underlying causes could be estimated. From this information the impact on the nature of close combat could be determined.

Figure 2 gives an overview of the study and shows these relationships: Lanchester equations for validation, generic CAEn scenarios for analysis, and the historic study and detailed CAEn scenarios for parameter exploration. The results from the CAEn simulation

[4] Simple scenario: A CAEn scenario designed to satisfy the assumption of Lanchester analysis.
Generic scenario: A CAEn attack/defence vignette conduct by doctrinal forces using doctrinal tactics on simplified terrain.
Specific scenario: A CAEn scenario that models a specific vignette including the effect of terrain on tactics.

were the centrepiece of the analysis. The tactics used in the simulation were representative of current Australian doctrine for deliberate company attacks against a platoon defence. The analysis of Lanchester equations was used to verify the CAEn simulations. The other tools were used to extrapolate the results of the generic CAEn scenarios to real world situations.

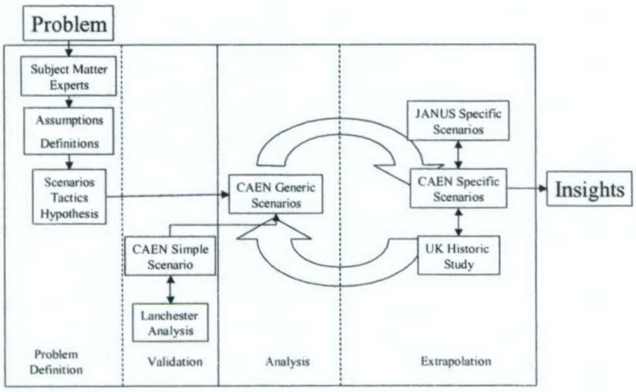

Figure 2: Outline of the Close Combat Study

3.2 Parameters used in the Close Combat Model

A range of parameters can be explored using this model of close combat. Table 1 lists the 'force level' parameters that were examined, and the options for each.

Table 1: Options for each parameters used

Parameter	Option
Type of fire	Aimed, Area, Combined
Tanks used	Not used, Used
Artillery used	Not used, Used
Type of terrain	Open, Restricted

CAEn models three types of small arms fire.

- **Aimed fire**: a target is acquired prior to discretionary engagement with fire. Its purpose is normally attrition of enemy strength.
- **Area fire**: a target area is identified and fired into without target entities being acquired. Its purpose is normally suppression.
- **Combined fire**: aimed fire is used if a target is acquired and area fire is used when there are no acquired targets.

This study examined the attackers and defenders using aimed or area fire (four possible combinations) along with the option where they both were using the combined strategy without restrictions on ammunition. The combined fire strategy of the infantry was used as the basis for the exploration of the support assets because this was judged to be the nearest realistic model of actual close combat.

The parameters and variables are inter-related and are at best a schematic representation of the 'real world' situation. The choice of using representative tactics on simplified terrain was felt to give the best balance of repeatable results that could be applied to a large range of scenarios and real attack tactics.

Table 2 illustrates the pros and cons of this modelling decision. It also provided a convenient link to other 'real world' studies conducted previously using CAEn. Although an artificial constraint from a practical military standpoint, the flat terrain and uniform vegetation provided a useful basis for comparing different capability mixes.

Table 2: Pros and cons of terrain and tactics representations

Tactics	Terrain representation	
	Simple	**Detailed**
Simple	Insight can be model specific, hence hard to apply to other situations Insight may be considered irrelevant as it can be unrealistic	Insights may be dismissed i.e. 'we wouldn't do it that way'
Complex	Insight can be extrapolated onto other terrains	Insight can be scenario specific and hence hard to generalize

4. Results

4.1 Insights from the UK Analysis of Historic Battles

An historical analysis, conducted by Defence Operational Analysis Centre (DOAC) in the UK (Thornton 1993), of tactical to battalion level battles during the American Civil War, the Franco-Prussian Wars, World War One (WWI) and the Northern European and Far Eastern Theatres of World War Two and Korea, produced the following insights, placed in context of the current study (*in italics*):

- Infantry defending positions in woods (*restricted terrain*) are two to three times less effective than infantry defending in open terrain, assessed by absolute casualties and Loss Exchange Ratio (LER).
- The effectiveness of infantry weapons in the attack is mainly in their ability to suppress.
- The effectiveness of infantry weapons in defence is in inflicting casualties (*attrition*).
- Artillery is about 30% less effective in supporting a defence in woods than in the open.
- Attacking casualties are reduced by about 40% by attacking at night (*limited ability to use aimed fire*).

- Medium machine gun support reduces attack casualties by about a third. *This supports the premise that the role of infantry weapons in the assault is to suppress the defences.*
- Attack casualties are reduced by 70% when facing an 'irresolute defence'. *This conclusion is interesting in that it may indicate the desired impact of manoeuvre. If the attack manoeuvre is not successful in forcing an enemy withdrawal prior to the attack, it may at least reduce the defenders' resolve. We have not modelled this type of effect on morale.*
- Target availability is a key factor on the defence's ability to inflict casualties on an attacker.
- The presence of fortifications increased the attack casualties by 65%.

4.2 Lanchester Equations

The seminal work by Lanchester (1916), based on WWI aircraft attrition, derived the equations and assumptions that are the basis for what are now known as Lanchester equations. Simple CAEn scenarios were developed to emulate the assumptions inherent in constructing a Lanchester model of combat to determine whether CAEn produced results consistent with those predicted by the equations as a method of investigating the internal consistency of the CAEn model. The outputs from these simple scenarios were fitted to two Lanchester models, the firer/firer (F | F or aimed firer) model and the firer target/firer target (FT | FT or area fire) model to try and determine the mechanism of attrition in each situation (an early study comparing CAEn and Lanchester demonstrated that when most Lanchester assumptions are met, CAEn results correlate, but quickly diverge as the CAEn scenarios become more complex (Bowley et al. 1998)). Fitting the CAEn data to an aimed fire and an area fire Lanchester model provided the basis for determining the dominant firing strategy in each scenario, or parameter combination. (Details of the Lanchester equations employed in the study can be found in Appendix A.)

After an initial examination of the data, our hypothesis was that the aimed fire scenarios modelled in CAEn reflected a Lanchester F | F model. In addition, the area fire scenarios modelled should reflect a Lanchester FT | FT model. If this hypothesis was valid then there would be a good fit between Lanchester and the CAEn generated data and this would be indicated by a low unweighted mean square error (MSE) in the fit.

Two simple scenarios were developed in CAEn to closely approximate the assumptions of the Lanchester F | F model: all units were fixed and limited to use the aimed fire algorithm. The terrain was flat and open vegetation was modelled, so that target acquisition was achieved between all units. The simulation settings were then changed to allow area fire to test the fit to the Lanchester FT | FT model. The MSE used as a test are summarised in Table 3. The table also includes the optimal fitted parameters b and r (as given in the equations) to two significant figures.

Appendix A.2 contains the curve fits from the Lanchester analysis.

Table 3: Lanchester results

Scenario	F | F			FT | FT		
	MSE	***b***	***r***	**MSE**	***b***	***r***
Aimed Fire	8.51	0.0086	0.026	8.45	0.00056	0.00039
Area Fire	71.85	0.0038	0.014	12.63	0.000405	0.00031

These results require careful interpretation because the null hypothesis appears to be satisfied for each parameter combination. It is important to emphasise that a close curve fit, measured by a low MSE, does not imply that the Lanchester model is the correct model of the attrition process. In this case we can only say that the CAEn results converge with the Lanchester model at a rudimentary level. Conversely, poor curve fits indicate a stronger relationship: that the model is inappropriate for the scenario.

We can rule out one Lanchester model as an appropriate method for describing the results. The F | F model is clearly not the appropriate attrition mechanism for describing the open Lanchester area fire scenario with a MSE of 71.85 (highlighted in Table 3). The MSE for the aimed fire scenario is not significantly different between the F | F and FT | FT models, so parameters can be chosen for b and r in either model that provide a close fit to the averaged CAEn attrition curves.

4.3 Generic Simulations

The generic wargames that formed the basis for this study are Australian Army doctrinal formal attack/defence scenarios simulated on simplified terrain. The two terrain types and indeed the scenarios that were used in the study can be considered as extreme conditions that may be encountered on operations. The assumption underlying this approach is that if there is no significant difference observable between the contributing elements and processes of close combat under the extreme conditions then we can state with some confidence that there is unlikely to be observable differences under all conditions that might be modelled. This leaves the question of what may actually occur under realistic terrain conditions open to conjecture, which we have attempted to balance in the study by reference to other data.

As discussed in section 3.2 the study deliberately balanced the complexity of the scenario required for realism with the simplicity required for repeatability.

The generic scenarios were used to examine the dependence of the LER on the force mixes and terrain representations using a game theory approach. Game theory is a mathematical method used to describe and solve a competitive optimisation problem (Murray 1973). Each pairing of choices is assigned a score and each side has conflicting goals in the optimisation (more details of the Game Theory Approach used are in Appendix B). In accordance with this method matrices were generated for the competitive options given in Table 1 — i.e., infantry only (the baseline scenario), individual support assets and the combined support assets. The LER from the CAEn game and the inherent uncertainty was used as the 'score' in determining the game theory outcome.

There has been much discussion on the uses and applicability of the LER as a measure of combat effectiveness in that it effectively integrates over many influencing factors. While we acknowledge the limitations of the approach, it was used in this study as a convenient basis for comparison because:

- it was consistent with the approach used in the UK Historical Study, and
- it was a measure that could be applied to the data in each of the techniques.

In addition, given that the LER is primarily used for relative comparisons in the combat outcomes and the study called for a review of trends rather than absolutes, it was felt that that the use of the LER as a measure was justified.

In addition to the LER-based analysis, graphs of the cumulative casualties over time were generated. These are given in Appendix C. These graphs show that two options that have the same overall result may reach that point with different casualties by time profiles.

4.3.1 Scenarios

The basic generic scenario used was a representation of a dismounted light infantry company attack on a light infantry platoon in a prepared (stage 2) defensive position. The base defending force was a platoon (total of 31) consisting of: three sections each with a sniper, a machine gun and seven AK-74, and a platoon HQ of four AK-74. The base attacking force was a company (total of 85) consisting of three platoons of three sections, each with two minimi and six Steyr; a platoon HQ with three Steyr; and a company HQ with four Steyr.

4.3.2 The Effect of Terrain on Factors Studied

4.3.2.1 Scale of Combat

In the baseline scenario it was possible to have 2635 different contact pairs (that is 31 x 85, i.e. attacker 1 contact with defender 1, 2, 3 etc, attacker 2 contact with defender 1, 2, 3, etc). An indication of the scale of combat can be measured by the percentage of possible links that are made during the scenario. In open terrain an examination of the CAEn results indicated that all possible links were established in all runs of the simulation. In restricted terrain however, an average of only 2% of all possible contact links were established. Figure 3 is a diagrammatic representation of the detection nets in open and restricted terrain. This result is consistent with the observations made in other studies (USMC 2001) that vegetation and other terrain culture features compartmentalise the combat and break it into a number of small, localised, engagements.

4.3.2.2 Mechanism of Close Combat

In the baseline scenario, no support assets were employed. The infantry firing tactic was restricted to one type of engagement in three variants; either aimed, area, or a combination of fire types. The aimed and area engagement types were run in open and restricted terrain variants, giving a 3x2 variant baseline. The LER scores for all variants were

compared using game theory, and the best firer tactic for the attacker and defender selected on this basis. The combined versus combined tactic was also run.

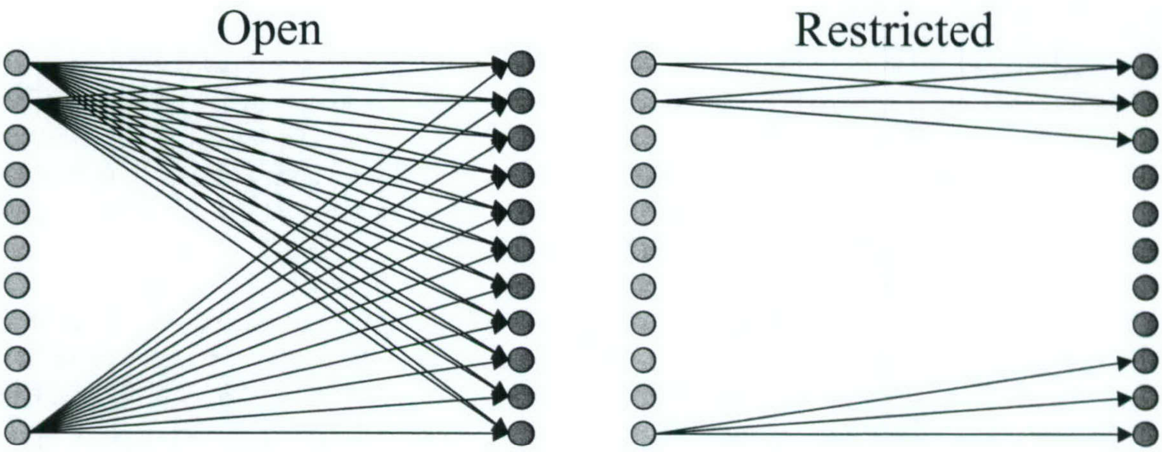

Figure 3: Representation of the contact/detection nets

In game theory one player tries to maximise payoff (maximise the minimum gain) independent of their opponent's actions while the second player is attempting to minimise their payoff (minimise the maximum loss). This is a minimax-maximin criterion applied to a zero sum game.

Applying this criteria to the results in Table 4 shows that for the baseline, the **attacker should always select aimed fire in open terrain** because this **always** improves the LER (from 0.75 to 0.99 when the defender uses area fire and from 0.17 to 0.29 when the defender uses aimed fire). Similarly, the **defender should always use aimed fire in open terrain** to gain an improvement in the LER. Consequently the analysis indicates that the best tactic to employ in open terrain was aimed fire for both the attacker and the defender.

Table 4: LER in the Baseline Scenario, open Terrain Variant

Attacker / **Defender**	Area Fire	Aimed Fire
Area Fire	0.75	0.99
Aimed Fire	0.17	0.29

The differences in the LERs, averaged over all the simulation runs, were tested and found to be statistically significantly at 95% confidence using difference of means testing. The LER for the combined versus combined tactic was found to be 0.21, which is similar to the preferred solution for both sides (aimed fire). It was found that when the engagement type was relaxed to allow the combination technique the majority of the time the entities selected aimed fire, as shown in Table 5. It is postulated that this was due to the ease of target acquisition in open terrain. The average time and range for the detections in each

terrain type support this contention, which requires further examination. Each side in the open detected outside the maximum effective range of the weapons (modelled as 700 m for the machine guns and 300 m for the rifles). This is summarised in Table 6. Figure 4 graphically shows the amount of aimed fire employed in open terrain.

Table 5: Relationship between engagement type used in the combined engagement type scenarios

	Open Terrain	Restricted Terrain
Aimed Fire	96%	8%
Area Fire	4%	92%

Table 6: Summary of Detections

	Blue		Red	
	Open Terrain	Restricted Terrain	Open Terrain	Restricted Terrain
Number of Detections/run	93%	0.37%	86%	0.13%
Average range of Detection (m)	765.9	57.8	766.2	69.5
Average Time of Detection (s)	41.3	2525.0	42.0	2459.2

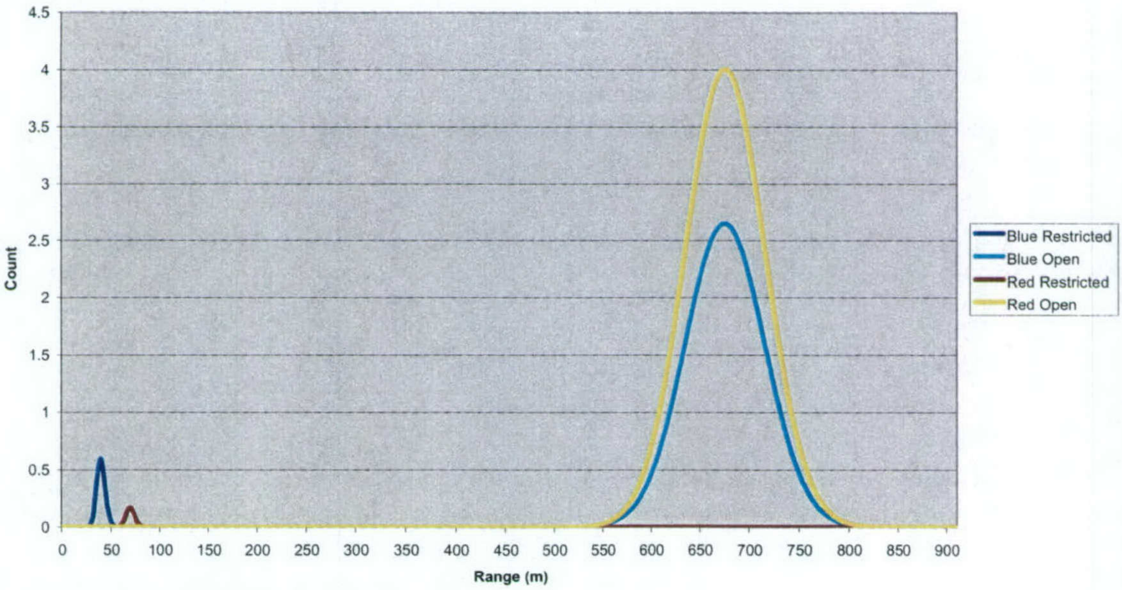

Figure 4: Distribution of Aimed Shots by Range

Analysis of the LER for the simulations in restricted terrain variants using the same method of analysis for open terrain indicates that the best type of engagement type for both attacker and defender was area fire, Table 7.

Table 7: LER in the Baseline Scenario, restricted Terrain Variant

Attacker **Defender**	Area Fire	Aimed Fire
Area Fire	0.76	0.27
Aimed Fire	6.9	0.83

The LER for the combined tactic was 0.68 and is similar to the preferred engagement type. The type of fire selected by the units in CAEn in the combined fire runs was again analysed and it was identified that the majority of the time they selected area fire, Table 5. We observe that this is consistent with a relatively more difficult target acquisition compared with open terrain. This postulate is supported by the detection data in Table 6 and the large change of the LER when the simulations restricted the attacker to assault using aimed fire only; 6.9, close to ten times the average of the other cases. These LER are all statistically significant different from each other.

The insight from this section is that where no supporting arms are employed, there is a difference in the best type of engagement type to employ in open and restricted terrain and that one fire tactic is not preferred for all conditions. While it is not possible to quantify exactly where the change occurs solely from this study, this supports the conclusion that the terrain has a significant impact on the nature of close combat, in that close combat is likely to be dominated by suppressive fire when detection ranges are within weapon range, and by aimed fire when detection range is greater than weapon range, which is the basis of our definition of open and restricted terrain types.

4.3.3 Impact of Supporting Elements

The influence of supporting arms on close combat was investigated in a series of variations to the baseline scenario in which supporting assets were introduced into the scenario. In this study there was no attempt made to modify the tactics of either side to make the best use of supporting assets, or to best combat them in defence; these aspects are covered in the specific scenarios referred to in the following sections. The support assets added were:

1. intimate support represented by Leopard AS1 and T-72 models, and
2. indirect fire support represented by 81 mm and 82 mm mortars models.

The employment options were again tested using game theory analysis of the LER. The best option in all cases, for both sides, was found to be employment of the supporting assets, as indicated in Table 8 through Table 10. In all cases the common competitive choice is found in element R_{22} of the game matrix, indicating that supporting assets improve the outcome for both the attacker and the defender in either open or restricted terrain scenarios. The Infantry only option is not the combined fire tactic run from the previous section. To ensure that the same random number stream was used for the same purpose in all scenarios, the additional assets were included even though they may not have been used. Consequently the infantry only option was rerun for this part of the analysis to ensure consistency. The LER are of the infantry only i.e. 85 blue and 31 red. In all scenarios there was less than 1 tank casualty for blue.

Table 8: Open terrain – tank support

Attacker / **Defender**	Infantry Only	Infantry & Tank
Infantry Only	0.24	1.40
Infantry & Tank	0.15	0.98

Table 9: Open terrain – artillery support

Attacker / **Defender**	Infantry Only	Infantry & Arty
Infantry Only	0.24	0.33
Infantry & Arty	0.18	0.30

Table 10: Restricted terrain – tank support

Attacker / **Defender**	Infantry Only	Infantry & Tank
Infantry Only	0.48	0.57
Infantry & Tank	0.48	0.53

Table 11: Restricted terrain – artillery support

Attacker / **Defender**	Infantry Only	Infantry & Arty
Infantry Only	0.48	0.66
Infantry & Arty	0.53	0.57

The magnitude of the impact varies between the asset type, the terrain and the side. In the open terrain tanks had a greater impact than artillery whereas in restricted terrain the artillery had a greater impact. The result is consistent with those of the previous section, where aimed fire is preferred in open and area fire in close terrain. However, this result may also reflect the peculiarities of the model to some extent; the tanks employ aimed fire in CAEn and the artillery employs area fire, which is representative of how the assets are normally employed in combat. In restricted terrain the supporting assets show a reduced benefit compared with the open terrain cases, which is constant with the UK Historical study result in the case of artillery. This result can be explained by the compartmentalised nature of the combat in restricted terrain noted in section 4.3.2 that limited the effective range of the tank's direct fire weapon. An additional reason for the reduction in effectiveness of artillery in close country is that the artillery acts to suppress the defence before the assault is within detection range and the adversary has time to recover to repel the infantry assault. In the case of the artillery the impact on the LER is small because although the method and timing of casualties are affected, there is minimal change to the LER as there is sufficient time for the defence to find targets and inflict almost the same number of casualties.

Figure 5 gives a breakdown of the casualties by source for the restricted terrain case Although the attacker's (blue) artillery destroys 56% of the defender's (red) force prior to close combat commencing, the attacker's casualties are only reduced by 25% if the defender did not have artillery, compared with both sides using it. This again reflects the compartmentalized nature of the restricted terrain battle.

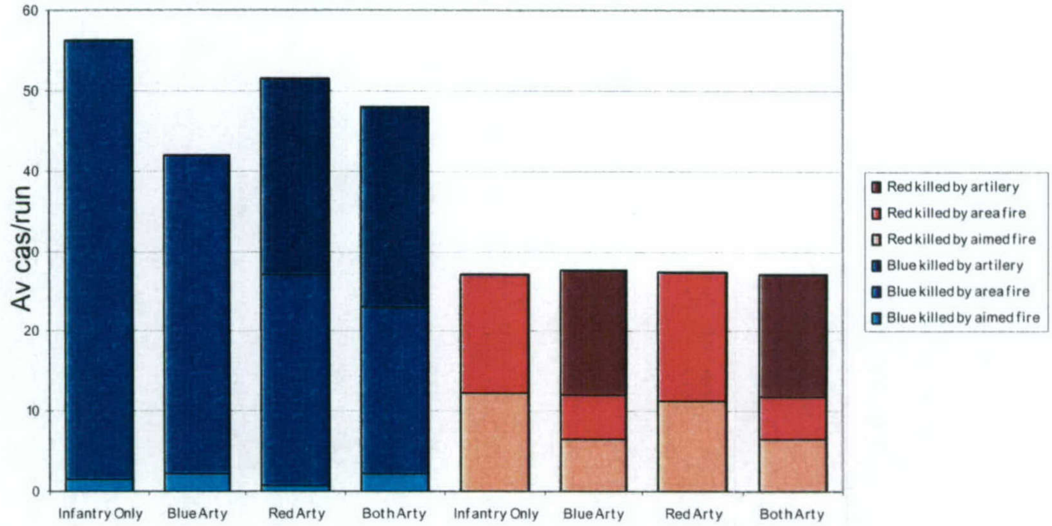

Figure 5: Investigation of the causes of casualties – average casualties per run by method in restricted terrain

Two additional options were modelled to assess the impact that the size of the attacking force has on the overall result. The options where both attackers and defenders had tanks were rerun with the attacking infantry reduced to platoon size. This was done for both open and restricted terrain. Table 12 shows the LER for the options. In both cases the attacker had a better result if they only had a platoon as the change in LER is due to the change in the attacker casualties.

Table 12: Impact on LER of a Reduction in attacking infantry numbers

Terrain	Attacking Infantry	
	Platoon	Company
Open	1.9	0.62
Restricted	1.1	0.64

4.3.4 Lanchester Analysis of the Generic CAEn scenarios

Lanchester attrition models were fitted to the generic scenarios where both sides were using the same type of fire. The mean square errors are summarised in Table 13. The table also includes the optimal fitted parameters b and r (as given in the equations) to two significant figures. Appendix A contains the curve fits from the Lanchester analysis.

Table 13: Lanchester results for the generic Scenario

Scenario	F|F			FT|FT		
	MSE	*b*	*r*	MSE	*b*	*r*
Open Aimed	13.84	0.00074	0.0058	30.14	0.000031	0.00012
Open Area	10.65	0.00067	0.0035	18.45	0.000044	0.000060
Restricted Aimed	12.24	0.00061	0.0024	13.65	0.000035	0.000036
Restricted Area	32.81	0.0026	0.014	15.12	0.00020	0.00028

As in section 4.2 the MSE results in Table 13 can be used to rule out a number of Lanchester models as an appropriate method for describing the results. Two distinct clusters appear in the MSE results in Table 13. The two largest MSEs, 32.81 and 30.14 are separated from the main cluster of values ranging between 10.65 and 18.45. The F | F model is clearly not the appropriate attrition mechanism for describing the restricted terrain area fire scenario with a MSE of 32.81, which belongs to the larger error cluster. Likewise the FT | FT model can also be ruled out for describing the open terrain aimed fire scenario since its MSE of 30.14 also belongs to the larger error cluster. The relative merit of the other descriptions can best be judged by inspecting the curve fits, since there is no significant difference in MSE.

4.3.5 Conclusions from Postulate testing

From the generic study the following statements can be made.

- Results are consistent with the aimed/area fire postulate (Postulate 1)
- Results are consistent with individual support asset postulate (Postulate 3)

The games theory matrices in Table 4 and Table 7 show that the preferred strategy for both sides supports the first postulate that aimed fire is likely to be the dominant mechanism establishing the criteria for defeat of a force in open terrain, whereas area fire will likely dominate in restricted terrain.

The game theory matrices shown in Table 8 to Table 11 support the third postulate that supporting assets provide an effective enhancement for establishing the defeat criteria for a force in either attack or defence when they are available.

The evidence from the study did not support the fourth postulate that the impact of support assets is additive to first order, as opposed to multiplicative. The evidence relating to this postulate is discussed in the remainder of this section.

Formal difference of means testing was carried out to determine what distinct subsets of results exist. The results of this can be seen in Appendix D. To simplify the analysis Table 14 indicates five subsets of parameter configurations that show no significant differences in their LERs. The subsets that were found are described in Table 15.

Table 14: Grouping of results that are not significantly different in open terrain

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	E	E	A	A
Arty	D	E	B	B
Tanks	D	E	C	C
All	D	E	B	B

Table 15: Description of the Subsets

Subset	Description
A	Occurs when the attacker has tanks and the Defender has no support assets
B	Occurs when the attacker has tanks and the Defender has artillery (with or without tanks)
C	Occurs when the attacker has tanks and the Defender has tanks only
D	Occurs when the attacker has no support assets and the Defender has tanks and/or artillery
E	The remaining 5 combinations

The first four subsets are distinct, with each member not being significantly different for the combinations in the subset but significantly different from those outside. These four distinct subsets ranked by attackers result are: A, C, B, D.

We found that distinct subsets of terrain did not exist in the restricted terrain based on the absence of statistically significant differences in the LERs. It is most likely that this is due partially to the reduced impact of support elements, resulting in smaller variations in the LER compared with the open terrain configurations.

From the viewpoint of the attacker, in the variations with supporting assets we note that the results for tank only and the results for both tank and artillery fall in the same subset when the defender's support was kept constant. Thus it can be concluded that the benefit of support assets is not additive.

Several apparent inconsistencies between the historical studies, the detailed CAEn simulations and the generic simulations emerge when formal difference of means testing is conducted across all the combination of results from the CAEn modelling. For example, in the open, artillery does not provide a significant benefit for an attacker using tanks. Therefore overall, the evidence from all methods does not support postulate 4. In the case of the generic CAEn scenarios this is most likely due to the authors making no attempt to synchronise the different elements of the combined arms teams as this was covered in the specific scenarios.

4.4 Specific Simulations

The simulations discussed in this section are drawn from recent studies conducted by Land Operations Division. The insights from the generic scenarios have been used to interpret the results of the specific studies; conversely the specific scenarios can be used to give context to the generic.

Two studies using the CAEn wargame and one using CASTFOREM were considered. All three of these studies used representations of real world terrain and tactics in an attack/defence scenario.

4.4.1 Tennant Creek Rural Study

A motorised infantry company (Blue) supported by the Battalion's direct and indirect fire platoons were modelled assaulting a Strike Platoon (infantry) that is reinforced with assets from the company Strike Battalion (Red). This study is reported in Lovaszy et al (2000) and Millikan, Castles and Brennan (2003).

The ORBAT for Blue in this scenario included:

- AH-1 W Cobra
- Leopard 1A4 tank
- Indirect fire Support
- Sniper Pair
- Recon Patrol
- Survl Ptl

The Opposing Force (OPFOR) included

- Mortar Sect
- Weapons Sect
- Anti-Tank Sect

The scenario investigated in this study was an attack across open terrain by a dismounted company with fire support from 4x ASLAV[5] (25 mm cannon) against a dug-in platoon supported by artillery and anti armour weapons.

The variants on this scenario were:

- Alternative 1. A troop of tanks in direct fire support.
- Alternative 2. A troop of Armed Reconnaissance Helicopter (ARH) in support.
- Alternative 3. A troop of tanks in intimate support.

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[5] ASLAV – Australian Light Armoured Vehicle

Figure 6 details the LER obtained by counting losses of systems, i.e. one ASLAV, mortar tube, or rifleman, and another LER by counting all personnel losses, i.e. an AT5 with a crew of three counting as three losses. The inclusion of any support asset in the attack increased the LER, i.e. improved the result for the attacker.

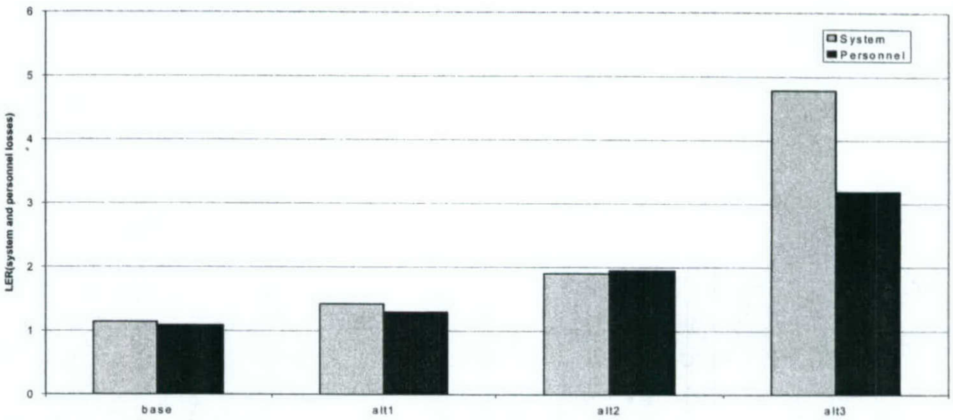

Figure 6: Average casualties across the range of options

The key insights from this study were:

- The tanks caused a greater increase in the LER when used in intimate support as they could engage depth positions and defensive systems directly threatening the infantry assault.
- The ARH was very effective in open terrain because of its long-range precision fire and speed (to deploy rapidly around the defence to flanking fire positions) and was useful in destroying high priority defensive weapon systems.
- The defensive indirect fire caused a large proportion of attacker casualties during the assault when not suppressed by counter-battery (CB) fire or ARH.
- There was a limit to the amount of direct fire support that was useful. The addition of a tank troop primarily changed the rate at which defending systems were destroyed, not the number. However this result depends on the simulation, as the defenders tend to 'fight and die' in the absence of morale models which would cause an 'irresolute defence' to withdraw or surrender after a certain level of losses was sustained.

4.4.2 Tennant Creek Urban Study

In this study Red was responsible for defending the northern sector of Tennant Creek township. Two phases of the Blue Motorised Company (Mot Coy) operation were investigated in this study, an assault across open terrain into the urban area and a fight through the urban area.

During the Assault across Open Terrain five variations were modelled:

- No obscuration and no CB fire
- Obscuration but no CB fire
- No obscuration but with aerial fire support (AFS)
- No obscuration but with CB fire
- Obscuration and CB fire

The results in Table 16 show a significant increase in the LER when artillery is available to conduct both obscuration missions and CB fire, far beyond that expected from the results of each option taken separately. The obscuration reduced the effectiveness of the defenders' direct fire and the CB fire the effect of their indirect fire. The helicopters targeted key defensive weapons systems. The overall conclusion was that the attack would fail during the assault, which is prior to the fight through, without artillery support.

Table 16: Results of the approach to the urban perimeter

Option	Casualties		
	Mot Coy	Red Side	LER
Baseline (no CB , Obsc or AFS)	38	12	0.31
CB Fire	26	21	0.83
CB Fire + AFS	9	25	1.39
Obsc, no CB Fire	13	9	0.74
Obsc + CB Fire	1	19	16.06

Four variations were modelled for the urban fight-through:

- no fight-through support system
- tanks allowed to use suppressive fire (SF) with machine guns only
- tanks allowed to use high explosive (HE) on precision targets
- AFS precision targets with HE

The results in Table 17 show a significant reduction in the attacker casualties when tanks are used in support and the rules of engagement allow it to use its main armament. The tank reduced friendly casualties significantly more than the AFS Helicopters.

Table 17: Result for Urban Fight through

Option	Casualties		
	Mot Coy	Red Side	LER
No support system	30	49	1.66
Tank (AGS), using MG only	22	50	2.20
Tank, using HE	14	50	3.53
AFS Helicopter	26	52	2.01

The key insights from this study were:

- Artillery Support is essential to close with a prepared defensive position.
- The AFS reduced casualties by 27.5% during the assault; however, it had difficulty influencing the fight through in the urban environment.
- The AFS system in open terrain must know the approximate locations of all enemies before embarking on its mission, due to its vulnerability in that terrain type.
- The tank in the urban fight-through scenario was able (with the right rules of engagement) to reduce casualties by as much as 52%.
- In circumstances where defending forward observers are able to monitor the assaulting infantry and CB fire cannot be brought to bear before the defending artillery redeploys, then the assault is unlikely to succeed.
- Quick response CB fire is very important in protecting the assault. In achieving this, the speed of the connection between the weapon locating radar and the Artillery assets is critical.

5. Discussion

A constant factor in this study is that employment of balanced combined arms teams remains the most effective and efficient solution for close combat. However, the studies emphasise that the balance of capabilities in a combined arms team depends critically on the nature of the enemy and the nature of the terrain. This confirms professional military judgement.

The details of the studies of close combat indicate that a balanced team includes capabilities of armour, artillery, mobility/counter mobility and infantry and that the important factor is the mix of armour and infantry, with respect to the type of terrain and the nature of the threat[6]. A UK historical study of close country fighting notes that in fact the infantry/armour ratio should be minimised. That is to use only enough infantry to protect the armour against infantry anti armour weapons, as the remaining infantry are very vulnerable (Thornton 1993).

Recent Israeli experience indicates that in urban close combat the minimum ratio is a troop of tanks supported by a battalion of infantry (LTCOL Kilcullen, personal communication). The phrasing here is not meant be provocative; the Israeli experience indicates that the primary role for the troop of tanks is protection for the engineer's bulldozer. Australian historical experience (Hall and Ross 2002) indicates that in very restricted terrain, like the jungles in Vietnam, the ratio between armour and infantry is a troop to a company. By

[6] While the simulations do not usually explicitly model mobility provided by engineers, the employment of counter mobility capabilities is a feature of the experiments.

contrast, US force structures for Europe and the Gulf were based doctrinally for open terrain with a ratio of a tank battalion to an infantry battalion.

An historical analysis of Vietnam bunker attacks (Hall and Ross 2002) gives an indication of the threshold at which the effect of supporting arms (as part of a combined arms team) is significant. The study indicates that in close country the threshold is set by the enemy and is where the enemy is able to conduct section level defensive operations. To date we have no conclusive evidence about a comparable threshold in either open or urban environments. However it is reasonable to assume a higher threshold in open terrain given normal (historical) combined arms groupings at unit level and a lower threshold (possibly individual snipers) in urban. More work is required in this area because it helps define the risk for operations, and determines where peace enforcement becomes warfighting (for the group in contact at least).

Infantry appear to provide three important characteristics to combined arms teams: they have excellent sensors (all weather, wide field of-view and motion sensitive capability), as individuals and small units, they have a very low signature and they provide a capability to secure fixed points that create manoeuvre dilemmas for the enemy. That is, infantry in defensive positions require an enemy to assault them with combined arms teams — which is a demanding task in terms of risk and resources. Infantry organisations have two key vulnerabilities; there is little passive protection from most battlespace weapons systems and they have limited organic firepower.

As components of the combined arms team, these strengths and weaknesses dovetail into the strengths and weakness of armoured vehicles, indirect fire support and mobility/ counter mobility assets, resulting in a balanced team. The key roles of infantry in a combined arms team can be seen as a relative constant in future close combat in the region. These roles are to:

- seek out the enemy,
- seize and hold ground, and
- protect indirect fire weapons and armoured vehicles from short range infantry weapons and infantry-based counter-battery techniques.

6. Conclusions

6.1 Demands of close combat

The simple model suggests that the nature of close combat changes significantly between open and restricted terrain. Success in close combat is dominated by the mechanism of attrition in open terrain and suppression in restricted terrain. This difference is possibly due to the difficulty of acquiring targets in restricted terrain. This observation is supported by the differences that were due to the differences in the detection nets.

The purpose of infantry weapons in defence is to destroy attacking systems. The purpose of infantry weapons in attack is to suppress the defence until the attack closes with the defence.

While not studied, we note that restricted terrain is likely to restrict mobility and firepower as well as communications and logistics. There is anecdotal evidence supported by overseas experts United States Marine Corp, Project Metropolis (USMC, 2001) that the training and leadership requirements increase for close combat in restricted terrain due to the need for complex integration of the intimate support elements (tanks) and the assault force (light infantry).

6.2 The level of force required

The scale of close combat changes between open and restricted terrain. In open terrain there is a possibility of single large battles where many defenders interact with many attackers. In restricted terrain close combat consists of a large number of few on few 'mini-battles'. The balance between the assault element and the intimate support element also changes between open and restricted; the infantry element can be reduced and effectiveness increased.

6.3 Capabilities required

Offensive close combat requires a capability to assault and engage in the close quarter battle. Modelling and historic analysis agree that success in offensive close combat is significantly improved by capabilities that:

- provide intimate support to the assault, and destroy threats to the assault group after all remote (from close combat) supporting fire has ceased;
- provide direct fire to support the assault as it finally closes with the defence; and
- provide indirect fire support to suppress the enemy's defences as the assault closes.

Defensive close combat requires a capability to hold ground. Success in defensive close combat is significantly improved by capabilities that:

- support the defence by destroying assaulting systems, and
- provide indirect fire support to suppress the assaulting force.

7. Further work

This study highlighted several areas that should be explored further. They include:

- Further exploration of target acquisition as this is a key requirement to enable aimed fire.
- Investigation of the impact of the enduring factors of close combat on the capabilities in future force structures.
- Investigation to define and explore the density of terrain that is the crossover between open and restricted terrain, i.e. where the effects of direct and area fire are balanced.
- Investigation in extremely complex terrain – urban.
- Exploration of the effect of changing the infantry tactics on the inclusion of the support assets.

8. Acknowledgements

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Appendix A: Lanchester Modelling

A.1. Robustness of results

After completing the simulation for a set number of runs, a 99% confidence limit was constructed on the option with the largest variation to ensure a sufficient number of CAEn replications were being conducted. This option was the attacker using aimed fire in the open terrain scenario. The number of replications was large enough to make a normal approximation to the sample mean reasonable and to assume the sample variance is a good approximation to the population variance. The maximum size of the confidence interval was (11.6, 16.8). This is a small enough interval for the purpose of Lanchester model parameter identification.

A.1.1 Firer | Firer Lanchester Model

A F | F attrition process models an aimed fire battle where the rate of attrition of each side is proportional to the numerical strength of the opposing side. Mathematically this can be expressed as

$$\frac{dB}{dt} = -rR \qquad \text{with } B(0) = B_0 \tag{3}$$

and

$$\frac{dR}{dt} = -bB \qquad \text{with } R(0) = R_0 \tag{4}$$

with B and R representing the number of units, dB/dt and dR/dt representing the attrition rate, and b and r representing the attrition rate coefficients in the Blue and Red forces respectively. This is the most common Lanchester model. The assumptions of this model are (Przemieniecki 1994) as follows.

1. Both forces must be continually engaged in combat.
2. Each unit or individual weapon is within the maximum weapon range of all the opposing units.
3. Collateral damage within the target area is negligible.
4. The attrition coefficients b and r also include the probabilities of the target being destroyed when hit.
5. The effective firing rates are independent of the opposing force level.
6. Each unit is aware of the location and condition of all opposing units so that its fire is directed only to live units or functioning weapons. When a target is destroyed, search begins immediately for a new target.
7. Fire is uniformly distributed over surviving units.

A.1.2 Firer Target | Firer Target Lanchester Model

The Lanchester FT | FT model is an attrition model for area fire, and so it does not assume concentration of firepower. The differential equations for the FT | FT model are:

$$\frac{dB}{dt} = -BrR \qquad \text{with } B(0) = B_0 \tag{5}$$

and

$$\frac{dR}{dt} = -RbB \qquad \text{with } R(0) = R_0 . \tag{6}$$

The first five assumptions from the F | F model are also assumed under the FT | FT model. However, the remaining assumptions differ.

6. Each unit is aware of only the general area in which enemy forces are located and directs its fire into this area without receiving any feedback information about the inflicted damage.
7. Fire is uniformly distributed over the area in which enemy forces are located.
8. All units are uniformly distributed over the area.

A.2. Fitting Lanchester to CAEn Simple Scenarios

The figures in the following sections show the CAEn results for the various scenario types and the corresponding fitted Lanchester model. Section A.2.1 gives the models for the CAEn scenarios that satisfy Lanchester assumptions and section A.2.2 the model for the CAEn generic scenarios.

Note that equations (3) and (4) are interdependent, and equations (5) and (6) are interdependent. Therefore fitting must satisfy both curves in each figure.

A.2.1 CAEn simple Scenarios

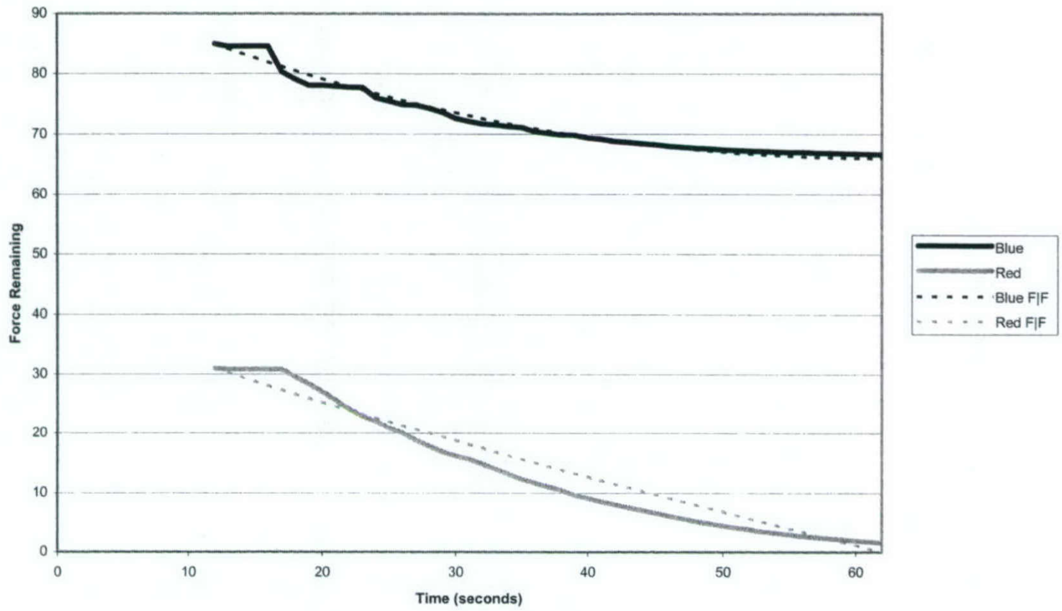

Figure 7: Lanchester F | F Curve Fit to CAEn Lanchester Aimed Fire Scenario

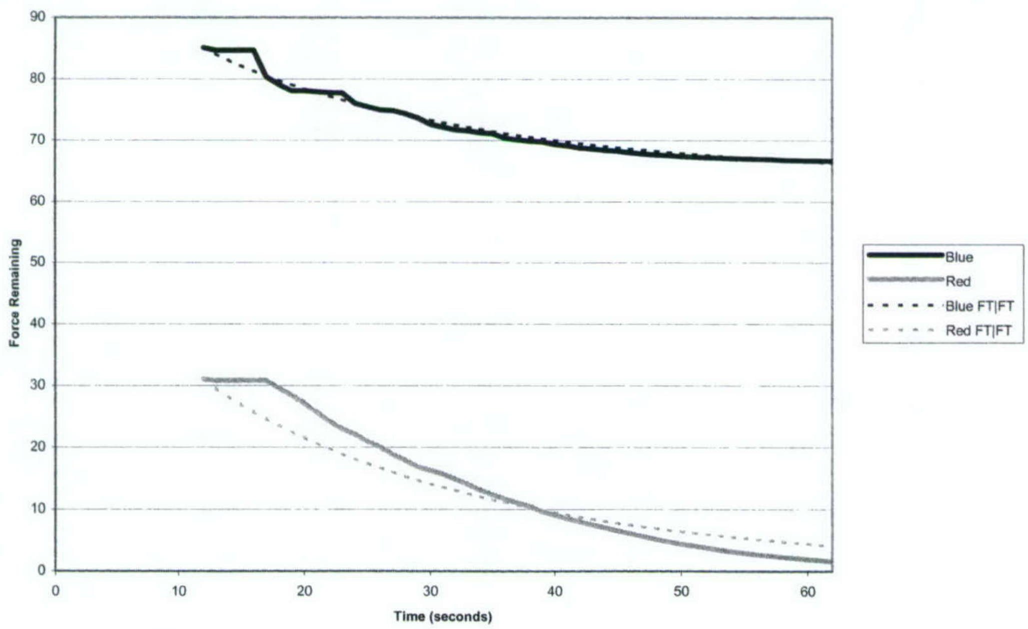

Figure 8: Lanchester FT | FT Curve Fit to CAEn Lanchester Aimed Fire Scenario

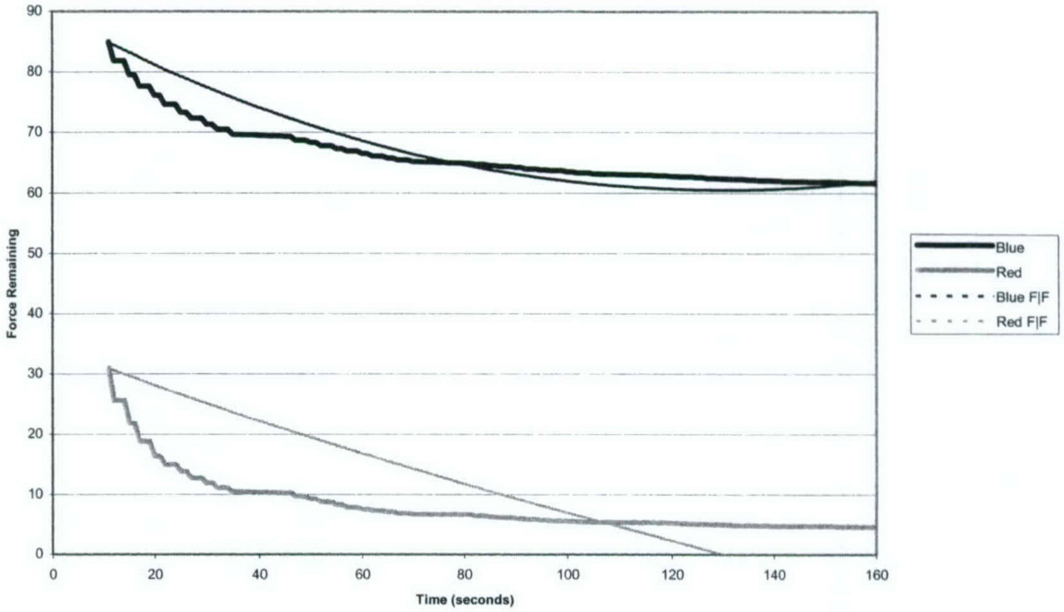

Figure 9: Lanchester F | F Curve Fit to CAEn Lanchester Area Fire Scenario

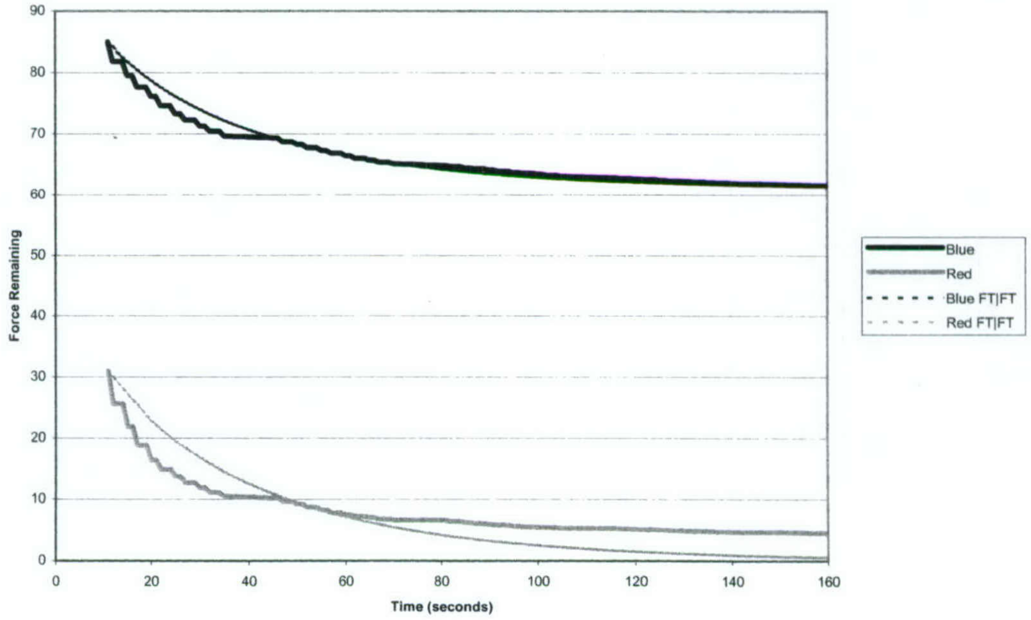

Figure 10: Lanchester FT | FT Curve Fit to CAEn Lanchester Area Fire Scenario

A.2.2 CAEn Generic Scenarios

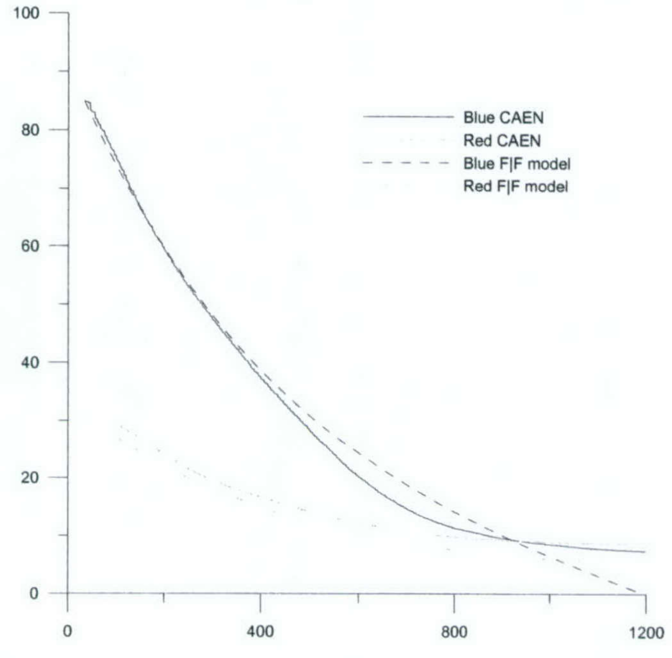

Figure 11: Lanchester F | F Curve Fit to CAEn Open Terrain Aimed Fire Scenario

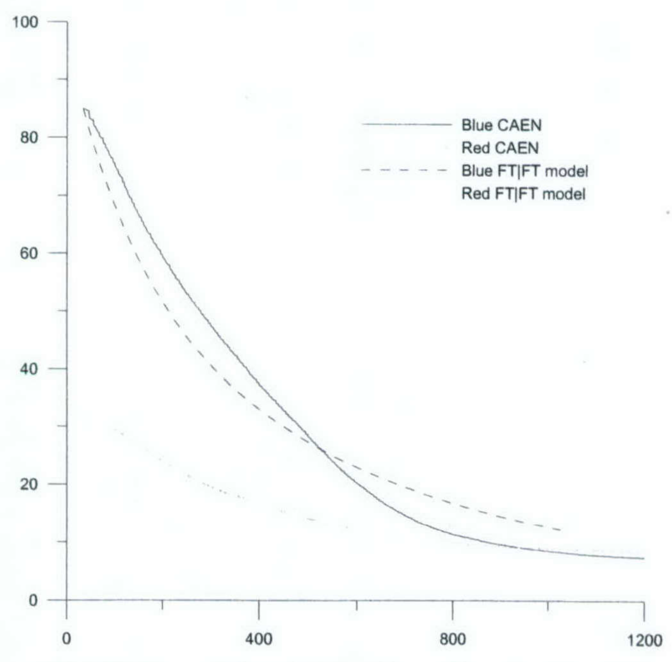

Figure 12: Lanchester FT | FT Curve Fit to CAEn Open Terrain Aimed Fire Scenario

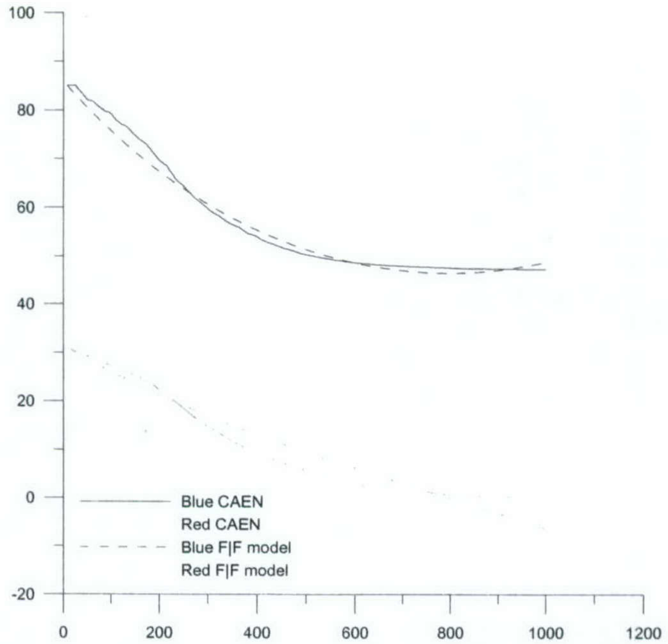

Figure 13: Lanchester F | F Curve Fit to CAEn Open Terrain Area Fire Scenario

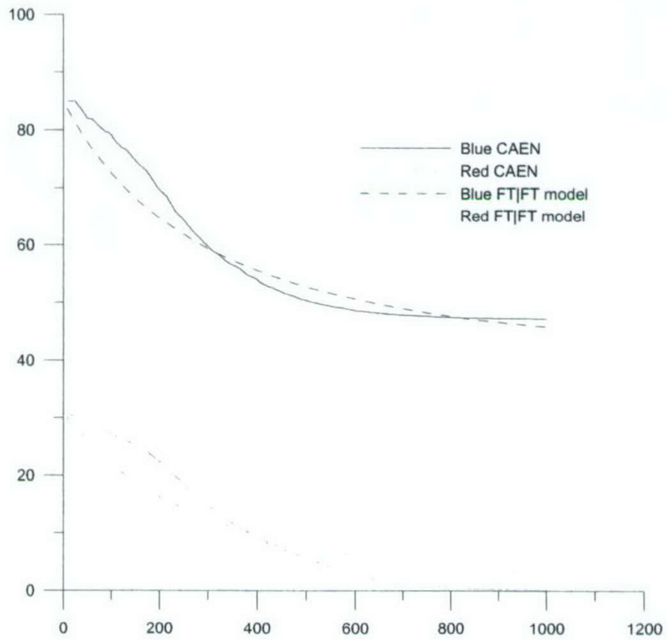

Figure 14: Lanchester FT | FT Curve Fit to CAEn Open Terrain Area Fire Scenario

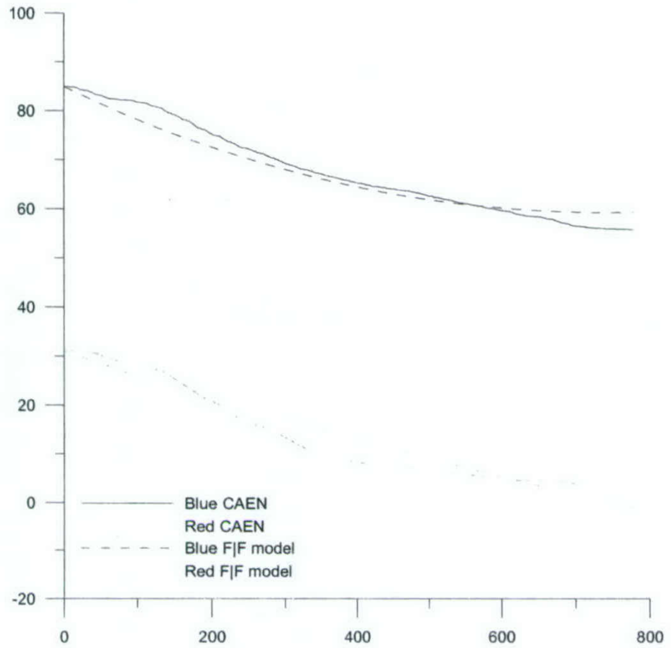

Figure 15: Lanchester F | F Curve Fit to CAEn Restricted Terrain Aimed Fire Scenario

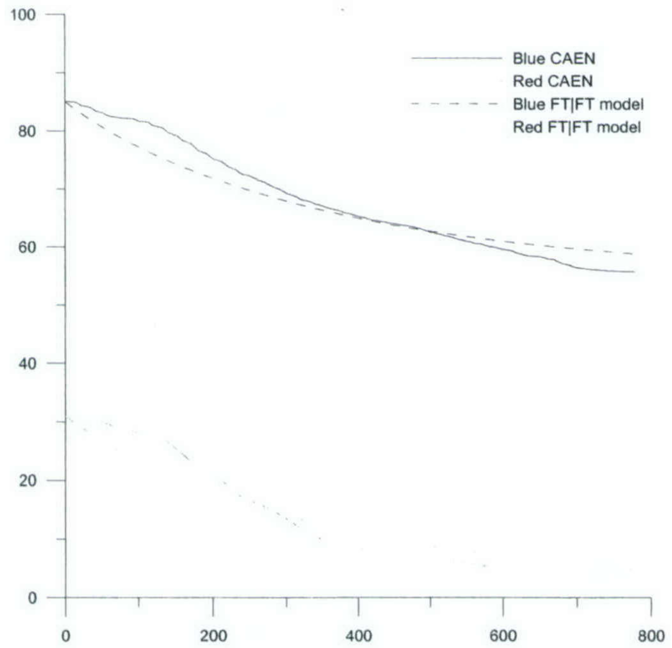

Figure 16: Lanchester FT | FT Curve Fit to CAEn Restricted Terrain Aimed Fire Scenario

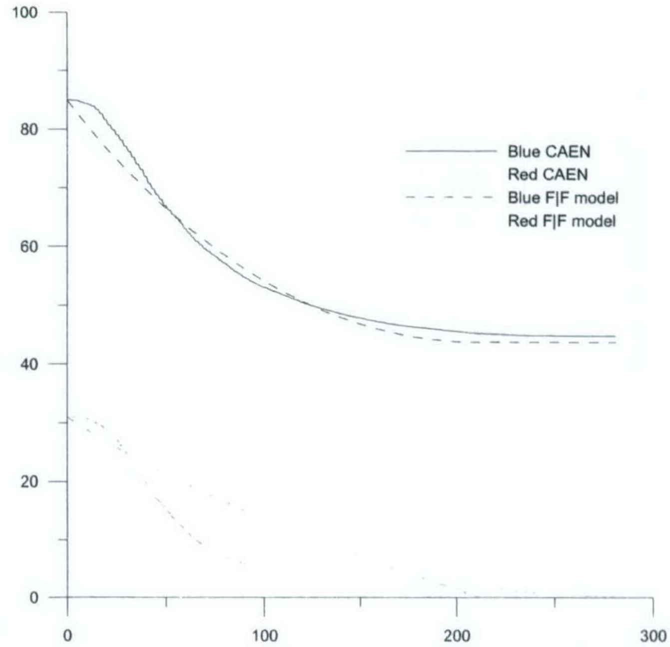

Figure 17: Lanchester F | F Curve Fit to CAEn Restricted Terrain Area Fire Scenario

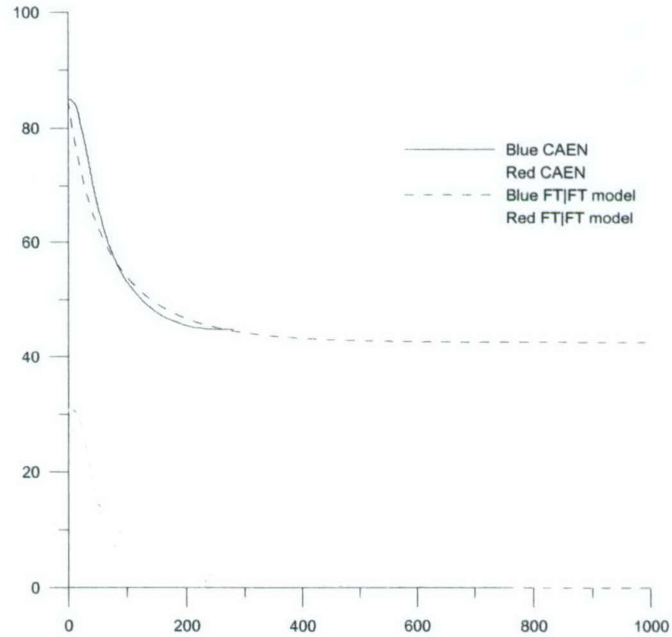

Figure 18: Lanchester FT | FT Curve Fit to CAEn Restricted Terrain Area Fire Scenario

Appendix B: Game Theory Analysis

A matrix was formed with each cell representing the score for a set combination. Table 18 shows how the matrix is formed using the result from each combination. R_{11} is the result when both player use option 1, likewise R_{12} is the result when player 1 uses option 1 and player 2 uses option 2.

Table 18: Formation of a Game theory matrix

Player 1 **Player 2**	Option 1	Option 2
Option 1	R_{11}	R_{12}
Option 2	R_{21}	R_{22}

The competitive basis for game theory says that player 1 tries to maximise the score while player 2 is trying to minimise it, i.e., both try to optimise the outcome. Using the scores that are given in Table 19 as an example, player 1 would chose option 2 as this is the prefer choice independent of the choice made by player 2. Similarly player 2 choses option 1 as this is the preferred choice independent of player 1's choice.

Table 19: Analysis of a Game theory matrix

Player 1 **Player 2**	Option 1	Option 2
Option 1	1	2
Option 2	3	4

Table 20 demonstrates if these two choices are made, a common solution of R_{12} will occur as the best competitive outcome for both. This technique can be applied to the modelling analysis using the LER as the score for each combination. Based on the definition of the scenario the attacker would prefer to maximise the LER and conversely the defenders would prefer to minimise it.

Table 20: Analysis of a Game theory matrix

Player 1 **Player 2**	Option 1	Option 2
Option 1	1	2
Option 2	3	4

Appendix C: Plots of Cumulative Casualties

Graphs of the cumulative casualties over time allow additional insights to be drawn on the differences between the options. The impact of the defender's support assets on the attacker can be seen in Figure 19 to Figure 22 in open terrain and Figure 27 to Figure 30 for restricted terrain. Likewise the attacker's support assets' impact on the defender can be seen in Figure 23 to Figure 26 for open and Figure 31 to Figure 34 for restricted.

C.1. Open Terrain

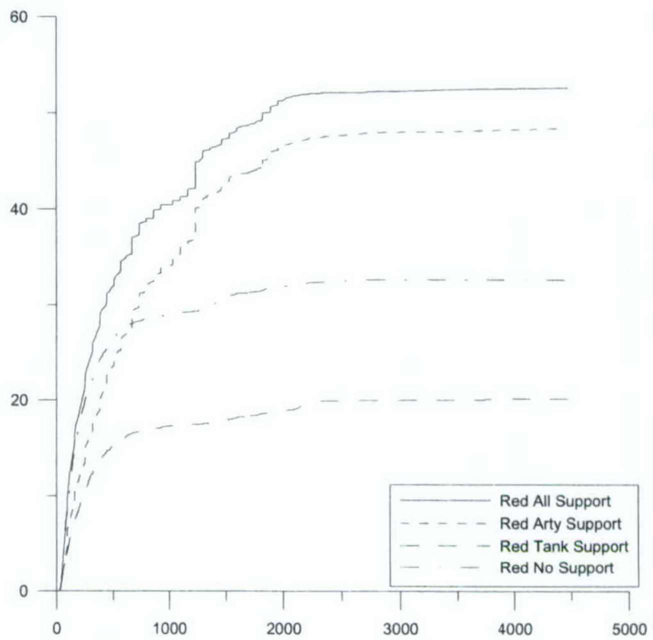

Figure 19: Blue with all Support Assets

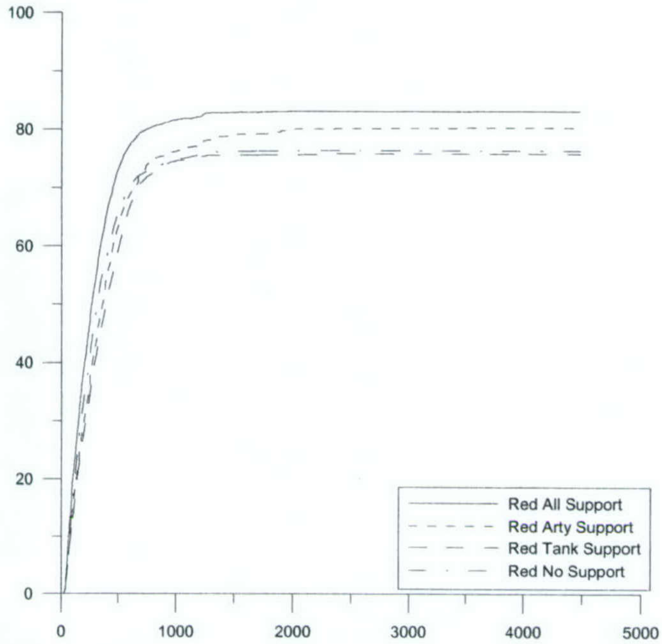

Figure 20: Blue with Artillery Support

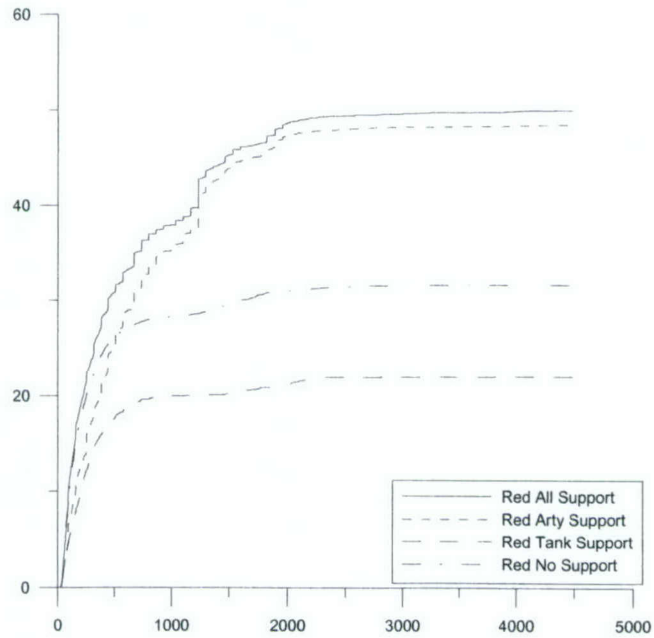

Figure 21: Blue with Tank Support

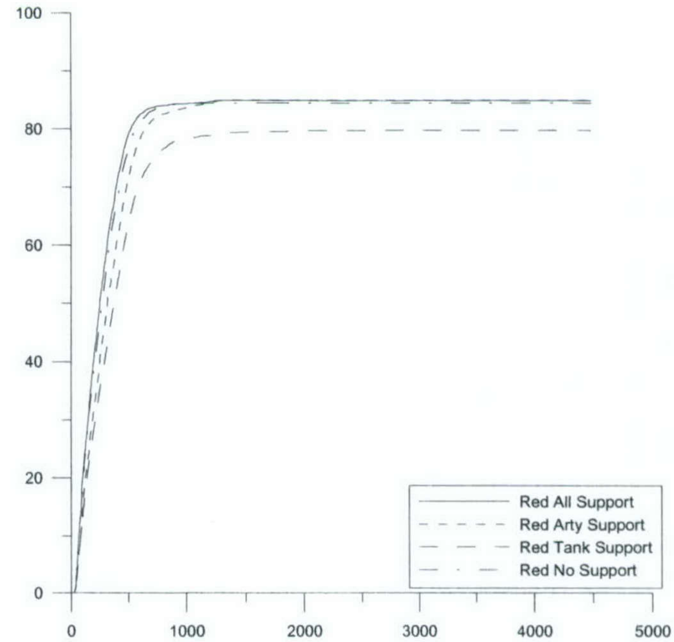

Figure 22: Blue with no Support Assets

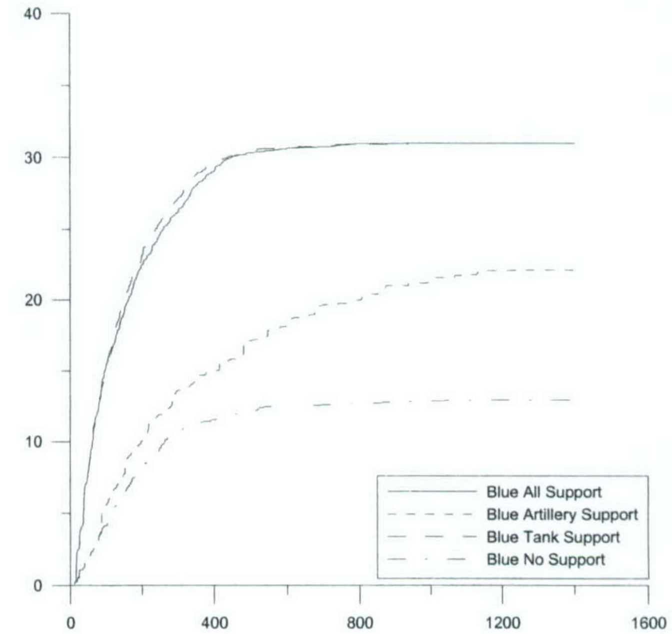

Figure 23: Red with all Support Assets

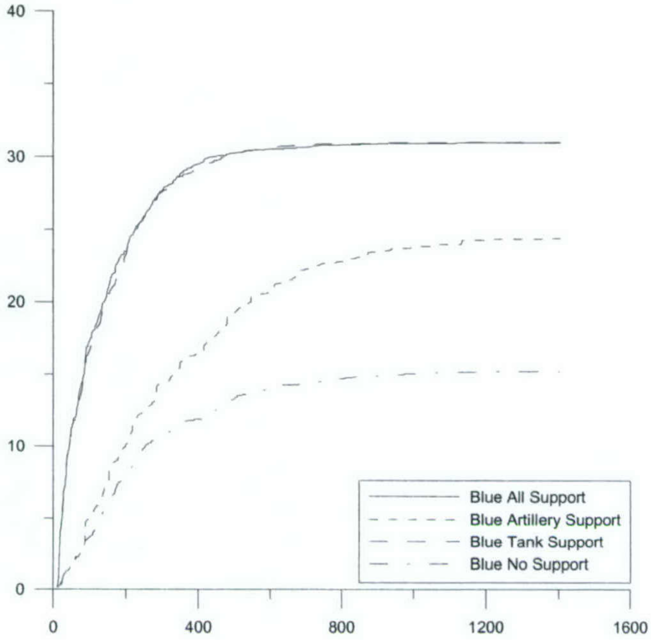

Figure 24: Red with Artillery Support

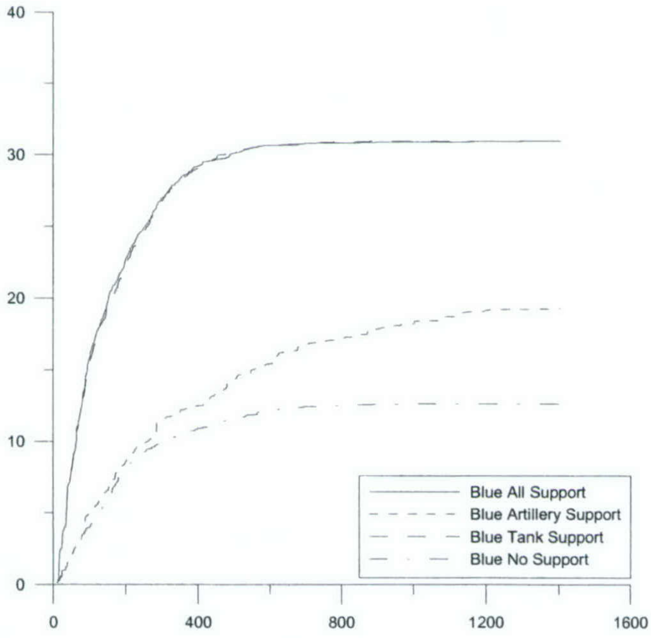

Figure 25: Red with Tank Support

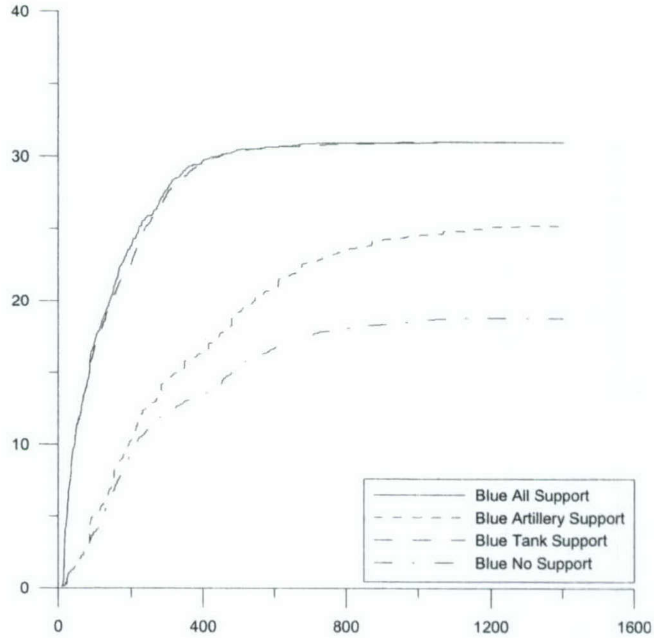

Figure 26: Red with no Support Assets

C.2. Restricted Terrain

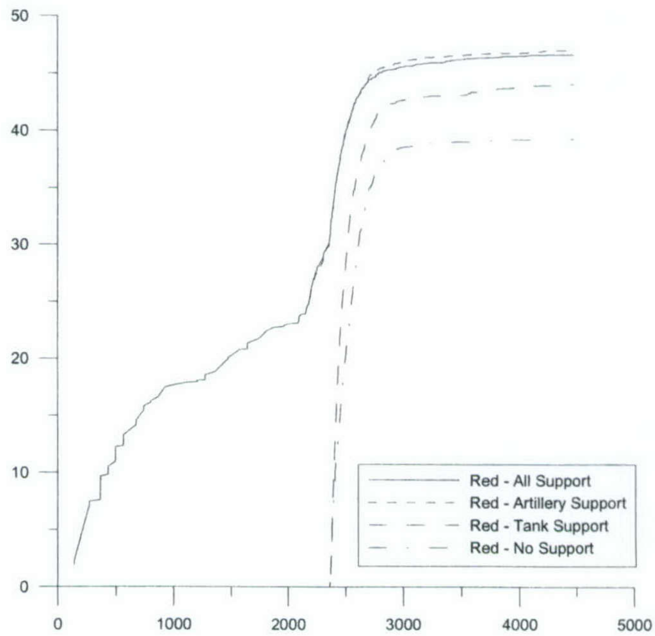

Figure 27: Blue with all Support Assets

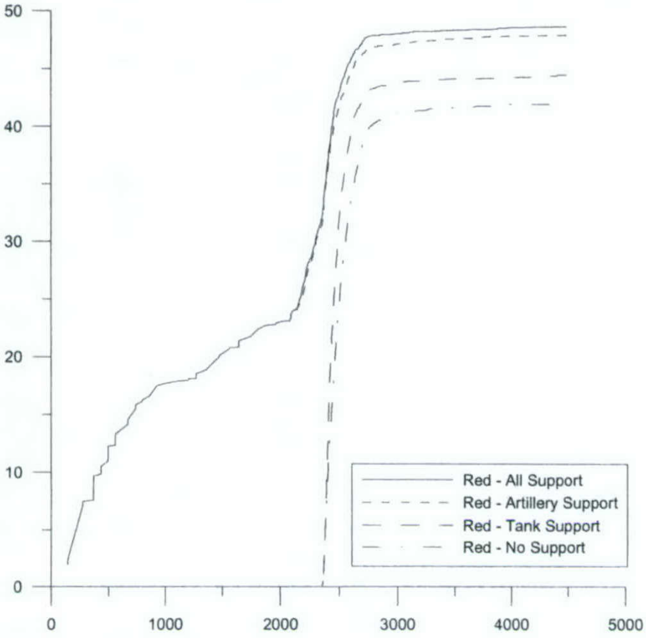

Figure 28: Blue with Artillery Support

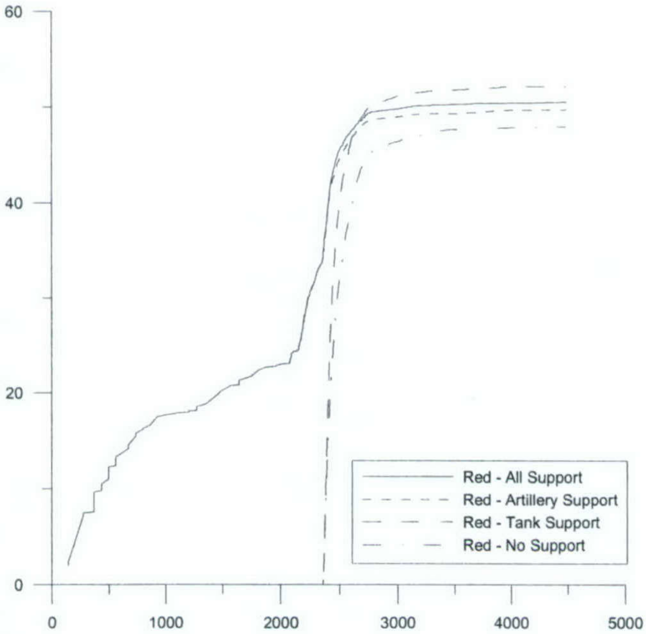

Figure 29: Blue with Tank Support

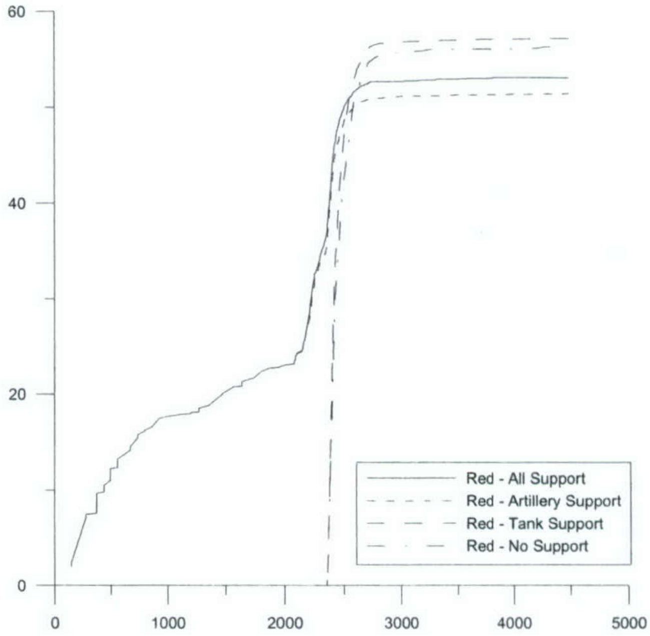

Figure 30: Blue with no Support Assets

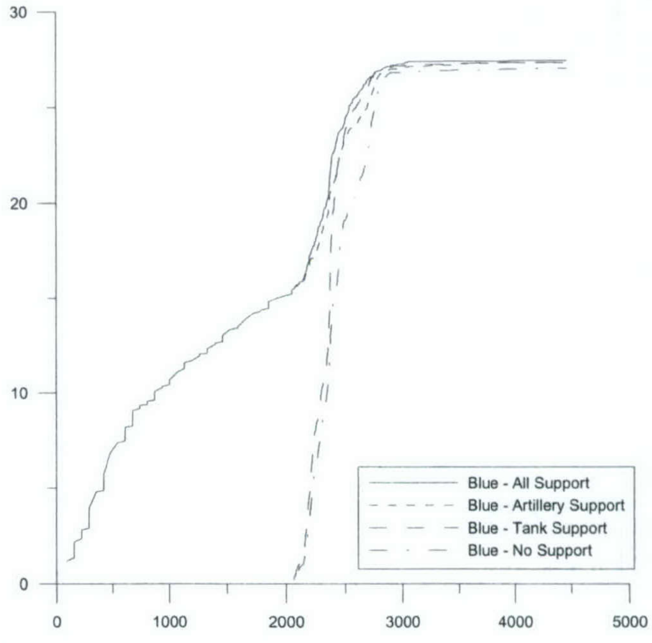

Figure 31: Red with all Support Assets

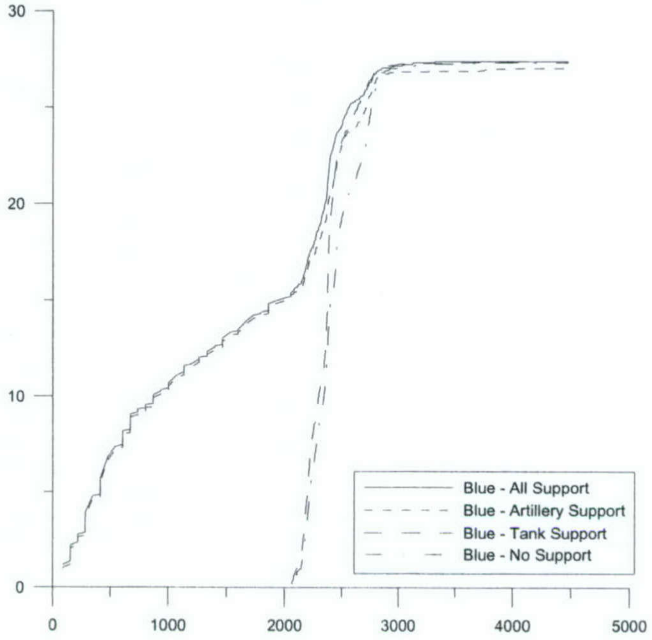

Figure 32: Red with Artillery Support

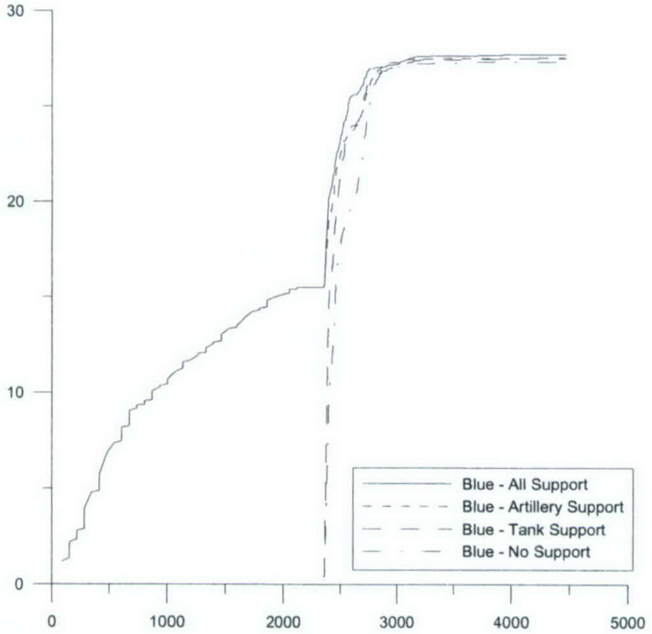

Figure 33: Red with Tank Support

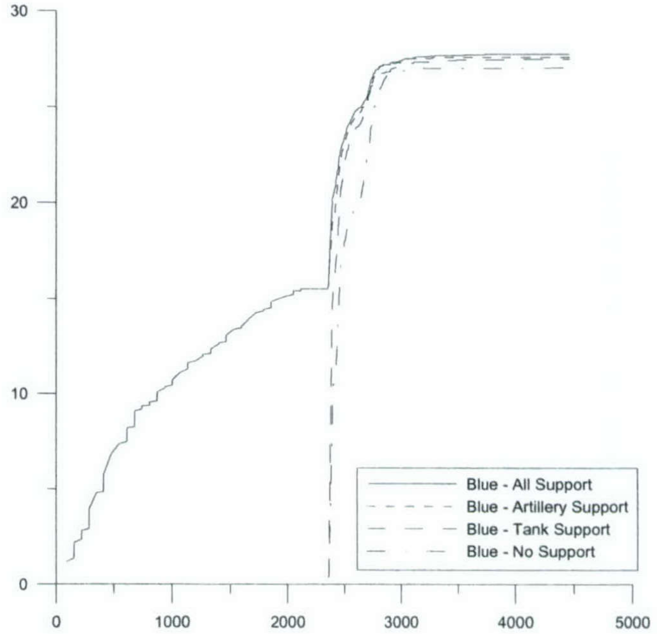

Figure 34: Red with no Support Assets

Appendix D: Significance Testing of Results

Difference of means testing was use to determine which combinations were significantly different from each other. The technique involves making an assessment based on the mean and standard deviation for two samples as to the likelihood that the samples were taken for the same population. In this study all testing was done at the 95% confidence level.

That the two combinations have the same mean can be rejected if the calculated z value exceeds a set threshold. Based on a 95% confidence limit and the sample size used in the CAEn study (n_1 and n_2), this threshold is 2. The z-value can be calculated as:

$$z = \frac{\bar{x}_1 - \bar{x}_2 - \delta}{\sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2}} \quad (7)$$

where

x_1, x_2, σ_1^2 and σ_2^2 are the mean and variance of the two options respectively.

Tables 22 to 37 show the significantly different results tabulated in Table 21.

Table 21: Loss Exchange ratios for the combination of support assets in open terrain

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	0.26	0.37	1.88	1.97
Arty	0.18	0.31	0.66	0.66
Tanks	0.15	0.30	1.18	1.06
All	0.15	0.27	0.63	0.61

In the tables in the remainder of this section the following shading coding is used.

Option being compared	Options that are different at the 95% level	Options that are **not** different at 95% level

D.1. Attacker (No Support) Defender (No Support) Option

Mean: 0.26
Variance: 0.03

Table 22: Difference of means, z-values (attacker (no support), defender (no support))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf		-2.3	-5	-7
Arty	2.3	-1.5	-10	-10
Tanks	3	-1.1	-8	-12
All	3	-.3	-10	-9

D.2. Attacker (No Support) Defender (Artillery) Option

Mean: 0.18
Variance: 0.008

Table 23: Difference of means, z-values (attacker (no support), defender (artillery))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	-2.3	-5	-6	-8
Arty		-6	-17	-18
Tanks	1.3	-5	-9	-14
All	1.2	-4	-18	-17

D.3. Attacker (No Support) Defender (Tanks) Option

Mean: 0.15
Variance: 0.006

Table 24: Difference of means, z-values (attacker (no support), defender (tanks))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	-3	-6	-6	-8
Arty	-1.3	-7	-19	-21
Tanks		-6	-10	-15
All	-0.06	-6	-21	-19

D.4. Attacker (No Support) Defender (Artillery and Tanks) Option

Mean: 0.15
Variance: 0.0006

Table 25: Difference of means, z-values (attacker (no support), defender (all))

Defender	Attacker			
	Inf	**Inf + Arty**	**Inf + Tanks**	**All**
Inf	-3	-6	-6	-8
Arty	-1.2	-7	-19	-21
Tanks	.06	-6	-10	-8
All		-7	-21	-19

D.5. Attacker (Artillery) Defender (No Support) Option

Mean: 0.37
Variance: 0.04

Table 26: Difference of means, z-values (attacker (artillery), defender (no support))

Defender	Attacker			
	Inf	**Inf + Arty**	**Inf + Tanks**	**All**
Inf	2.3		-5	-7
Arty	5	1.3	-7	-7
Tanks	6	1.6	-7	-10
All	6	2.5	-7	-6

D.6. Attacker (Artillery) Defender (Artillery) Option

Mean: 0.31
Variance: 0.01

Table 27: Difference of means, z-values (attacker (artillery), defender (artillery))

Defender	Attacker			
	Inf	**Inf + Arty**	**Inf + Tanks**	**All**
Inf	1.5	-1.4	-7	-5
Arty	5		-13	-12
Tanks	7	0.4	-12	-8
All	7	1.8	-11	-12

D.7. Attacker (Artillery) Defender (Tanks) Option

Mean: 0.30
Variance: 0.01

Table 28: Difference of means, z-values (attacker (artillery), defender (tanks))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	1.1	-1.6	-5	-7
Arty	5	-0.4	-11	-12
Tanks	6		-8	-12
All	6	1.2	-12	-11

D.8. Attacker (Artillery) Defender (Artillery and Tanks) Option

Mean: 0.27
Variance: 0.007

Table 29: Difference of means, z-values (attacker (atillery), defender (all))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	0.3	-2.5	-5	-7
Arty	4	-1.8	-14	-15
Tanks	5	-1.2	-9	-13
All	6		-15	-14

D.9. Attacker (Tanks) Defender (No Support) Option

Mean: 1.88
Variance: 2.82

Table 30: Difference of means, z-values (attacker (tanks), defender (no support))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	5	5		-0.2
Arty	6	5	4	4
Tanks	6	5	2.2	2.7
All	6	5	4	4

D.10. Attacker (Tanks) Defender (Artillery) Option

Mean: 0.66
Variance: 0.02

Table 31: Difference of means, z-values (attacker (tanks), defender (artillery))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	10	7	-4	-6
Arty	17	12		-0.06
Tanks	19	11	-5	-6
All	19	14	0.9	1.8

D.11. Attacker (Tanks) Defender (Tanks) Option

Mean: 1.18
Variance: 0.34

Table 32: Difference of means, z-values (attacker (tanks), defender (tanks))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	8	7	-2.2	-3
Arty	9	8	5	5
Tanks	10	8		1.0
All	10	9	5	5

D.12. Attacker (Tanks) Defender (Artillery and Tanks) Option

Mean: 0.63
Variance: 0.01

Table 33: Difference of means, z-values (attacker (tanks), defender (al))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	10	7	-4	-6
Arty	18	12	-0.9	-1.0
Tanks	21	12	-5	-7
All	21	15		1.0

D.13. Attacker (Artillery and Tanks) Defender (No Support) Option

Mean: 1.97
Variance: 1.75

Table 34: Difference of means, z-values (attacker (all), defender (no support))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	7	7	0.2	
Arty	8	7	5	5
Tanks	8	7	3	4
All	8	7	5	6

D.14. Attacker (Artillery and Tanks) Defender (Artillery) Option

Mean: 0.66
Variance: 0.01

Table 35: Difference of means, z-values (attacker (all), defender (artillery))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	11	7	-4	-5
Arty	18	12	0.06	
Tanks	21	12	-5	-6
All	20	15	1.0	1.99

D.15. Attacker (Artillery and Tanks) Defender (Tanks) Option

Mean: 1.06
Variance: 0.11

Table 36: Difference of means, z-values (attacker (all), defender (tanks))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	12	10	-2.7	-4
Arty	14	12	6	6
Tanks	15	12	-1.0	
All	15	13	7	7

D.16. Attacker (Artillery and Tanks) Defender (Artillery and Tanks) Option

Mean: 0.61
Variance: 0.01

Table 37: Difference of means, z-values (attacker (all), defender (all))

Defender	Attacker			
	Inf	Inf + Arty	Inf + Tanks	All
Inf	9	6	-4	-6
Arty	17	11	-1.8	-1.99
Tanks	19	10	-5	-7
All	19	14	-1.0	

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19. ABSTRACT
An initial investigation of the nature of future close combat derived and tested two possible enduring mechanisms for the conduct of close combat – attrition and suppression. A suite of analytical tools, including closed simulations, wargames, mathematical analysis and historical analysis, was used to establish loss exchange ratios (LER) for a number of scenario variants. The LER was used as the primary measure of effectiveness to investigate the dependence of combat success on the composition of the combined arms teams and the dependence of combat outcome on terrain. The analysis concludes that attrition is the dominant mechanism in "open" terrain and suppression in "close" terrain and that this is likely to endure, while improvements in sensors and weapon systems will gradually change the terrain types that are considered "open" and "close". The utility of combined arms teams was demonstrated by a significant reduction in absolute casualties and LER.